[redacted]

NRL Memorandum Report 1537
Copy No. 75 of 75 copies

INFORMATION ON OVER-THE-HORIZON RADAR
PART II

(UNCLASSIFIED TITLE)

F. E. Boyd, F. M. Gager, J. M. Headrick, G. K. Jensen,
E. Lurker, LCDR, USN, G. A. Morgan, and E. N. Zettle
U.S. NAVAL RESEARCH LABORATORY
in cooperation with
P. Sharki, A. Briggs, and D. Montana
ROME AIR DEVELOPMENT CENTER

1 June 1964

U. S. NAVAL RESEARCH LABORATORY
Washington, D.C.

[redacted]

[redacted]

NRL Memorandum Report 1537

INFORMATION ON OVER-THE-HORIZON RADAR, PART II (Preliminary Issue)

F.E. Boyd, F.M. Gager, J.M. Headrick, G.K. Jensen, E. Lurker, LCDR, USN, G.A. Morgan, and E.N. Zettle of the Naval Research Laboratory in cooperation with P.Sharki, A. Briggs, D. Montana and the staff of the Rome Air Development Center

1 June 1964

U.S. NAVAL RESEARCH LABORATORY
Washington, D. C.

[redacted]

CONTENT

This report contains Detailed Work Statement Specifications for AN/FPS-95.

PROBLEM STATUS

This is an interim report on one phase of the problem; work is continuing.

AUTHORIZATION

USAF MIPR (30-602) 64-3412 to the Naval Research Laboratory
dated 26 March 1964
NRL Problem 53R02-42

[redacted]

CONTENTS

[redacted]

PRELIMINARY WORK STATEMENT SPECIFICATIONS FOR AN/FPS-95

INTRODUCTION

There is interest in a HF, operational prototype radar for overseas installation which should be operable over a full eleven year sunspot cycle. There is a specific mission to be accomplished at an already chosen site. Due to the nature of the targets of interest and desired display information, the system is stated to be of the coherent pulse doppler type. This preliminary work statement specification outlines desired technical objectives which must be read against the state of the art, cost trade offs, etc., for a versatile, flexible system with negligible development items but one having growth potential.

SYSTEM DESIGN PHILOSOPHY

BROADBAND AIMS

The objectives for the antenna and rf power sources envision a broadband versatile radiating system fed by broadband power sources associated with real and near real time signal processing modes which are quite firm. The degree to which some eventual contractor's state of the art can approach or even exceed the technical objectives will determine the ease with which the mission elements can be altered by increasing data rate, radiated power or providing additional functions such as automatic data handling or additional display means such as acceleration gates.

FREQUENCY RANGE

Technical objectives can readily outline an ideal frequency range for the task at hand, though the state of the art and cost trade offs can define a more realistic frequency range. This statement applies particularly to the antenna, steering matrices, duplexers and rf powering components. The suggested frequency ranges of interest are enumerated under the system component heading, antenna.

AZIMUTHAL COVERAGE - OPERATING FREQUENCY

It is visualized that the azimuthal angle of interest could be composed of three sectors and the sectors made up of a certain number of beamwidths. For each beamwidth there is a minimum and maximum range where at any one time one might require two or three nominal frequencies and appropriate prf's to illuminate the full range. These nominal frequencies are not usually critical and one can visualize a megacycle or so about these nominal frequencies where successful operation could be achieved. Thus the momentary frequency of operation is one where a "look-through-for-idle-channel" mechanism is maintained in the band about the nominal frequencies, one at a time, so that a recognized idle channel can be used to call up the appropriate transmit frequency. This mode of operation could be programmed in the band or randomly operated. Such a mode offers the maximum chance to obtain useful data while causing a minimum disturbance to adjacent channel or co-channel users. This mode will provide some anti-jam features particularly when associated with a variable dwell time on any one frequency. The minimum dwell time for some targets may be less than a second whereas others may be twenty seconds or more.

Return to the concept of the azimuth angle composed of three sectors. In the minimum rf power phase a powering of say 200 Kw could be applied to the chosen sector. Additional units of 200 Kw could be added to power the other sectors, the full 600 Kw could be applied at three frequencies, one sector at a time, or the 600 Kw could be applied at one frequency. This growth in power concept, which would be initiated by an increased data rate requirement, lends flexibility to the mode of transmission where the nominal frequencies could be transmitted one at a time or three simultaneously. In addition to the operating frequency agility described, it is proposed to obtain assignment of at least one to three operating frequencies in each megacycle of the desired frequency range.

TARGET CHARACTERISTICS

NRL experience shows that aircraft targets are characterized in a coherent pulse doppler radar by:

(a) Constant velocity line spectrum (on course),

(b) Discrete radar range,

(c) Slow amplitude fades (tens of seconds to tens of minutes), and

(d) Small HF average echoing area (hundreds of square meters).

NRL experience shows that missile targets are characterized in the altitude range between launch pad and the E-layer (100 Km) for powered flight by:

(a) Acceleration line spectrum,

(b) Discrete radar range,

(c) Small echoing cross section, ranging from tens of square meters at low altitude to thousands of square meters as the E-layer is approached, where the large cross sections are both a function of altitude and missile power plant, and

(d) Fast signal fades (order of seconds).

NRL experience shows that missile targets are characterized in the altitude range E-layer (100 Km) to F-layer (200-300 Km) for powered flight by:

(a) Accelerating line spectrum submerged in a large return exhibiting a frequency diffusion of hundreds of cycles and a very distinctive appearance relative to natural phenomena,

(b) Large echoing cross sections exhibited by diffuse return with the size a function of illuminating frequency, and

(c) Target discrete in radar range.

Experience shows that missile targets are also characterized by some secondary effects, while being powered in the upper atmosphere, such as:

(a) Distinctive forward paths are set up and can be seen in the backscatter with frequency diffusion similar to that of the exhaust echoes. This is a prompt effect, occurring while the missile is in the layer, and the whole shows some range discreteness, and

(b) Ionospheric turbulence increase due to powered missile penetration results in broadening of backscatter spectrum.

TARGET DETECTION PROBLEMS

NRL experience shows that the foremost problems are:

(a) In the case of skin tracks, very large earth backscatter to signal ratios (70 to 80 db normally, sometimes larger). A guide to clutter spectrum and clutter spectrum reduction is found in NRL Reports 4976(U) and 5589(C), and NRL knowledge is available,

(b) Meteor echoes (principally trails at ionospheric wind velocity)

(c) Co-channel use (interference),

(d) Adjacent channel use (interference),

(e) Large near range moving targets,

(f) Securing and recognizing desired illumination, and

(g) Obtaining optimum trade-off between doppler ambiguity and range ambiguity.

TARGET DETECTION PROBLEM SOLUTIONS

NRL experience shows that effective solutions to the target detection problems enumerated above include:

(a) Employment of rejection comb filtering of the backscatter (note that targets with low relative radial velocity are removed),

(b) Secure wide, linear range in the signal conversion-receiver chain, including the signal processor,

(c) Use of range gating in the signal processor and then narrow band filtering (as narrow as 1/20 cps can be useful in S/N improvement for aircraft). The number of filters required may be reduced by sampling and time compression,

(d) Present doppler versus range panoramic display and doppler spectrum versus time for ranges of interest display with some selection in width of resolution bandwidths desirable. This technique provides an approximation to matched filtering for aircraft and the frequency panoramic displays are very powerful for missile recognition. Matched acceleration gating is desirable for low altitude missile detection and is feasible with a time compression signal processor,

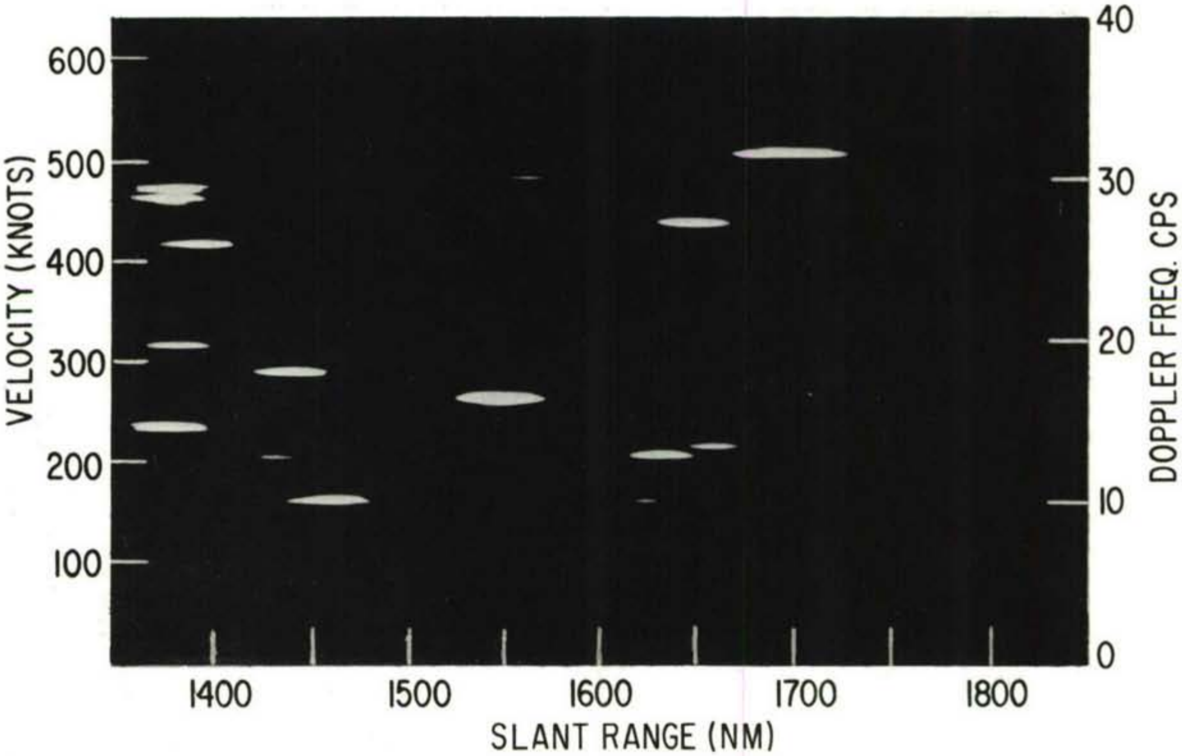
(e) Keep repetition rate as high as possible consistent with range determination (note that this rate can frequently be higher than for a line of sight system due to the skip zone). A wide available doppler provides several important advantages,

(f) Use of periodic sounding of backscatter distribution with range both for operating frequency and repetition rate selection, and

(g) Select operating frequencies on a quietness basis with movement agility.

INFORMATION DISPLAY FORMAT

The display of detected aircraft targets desired for any illuminated area is one where the doppler or relative radial speed is indicated vs range in a manner shown by the example Fig. 1. The tracking of any one of these targets should be understood to consist of a time-range plot where the slope is the relative radial speed. An example of such a track is that of Fig. 2 which is that of an incoming target. It is also noted that it should be always known in which beam the target is grossly located and, when desired, the azimuthal angle of arrival is determinable from split beam techniques.



Operating Conditions

Date - 12/13/63 3:35 PM EST.

Freq. - 18.036 MC

Ant. - Bearing 279° (looking west from NRL-CBA)

Antenna - 3db Beamwidth - 30°

Free Space Gain - 11.6 db

Power Output - 100 KW Average

1st hop backscatter - 1000 NM - 1950 NM

Calibration signal at 31 cps and 1700 NM corresponds to a 10 μ volt signal at antenna terminals

Fig. 1 - Aircraft echoes from a 450 naut. mi. sector west of Denver, Colorado with azimuthal coverage from Helena, Montana in the north to White Sands, N.M. in the south. At least 9 aircraft echoes visible.

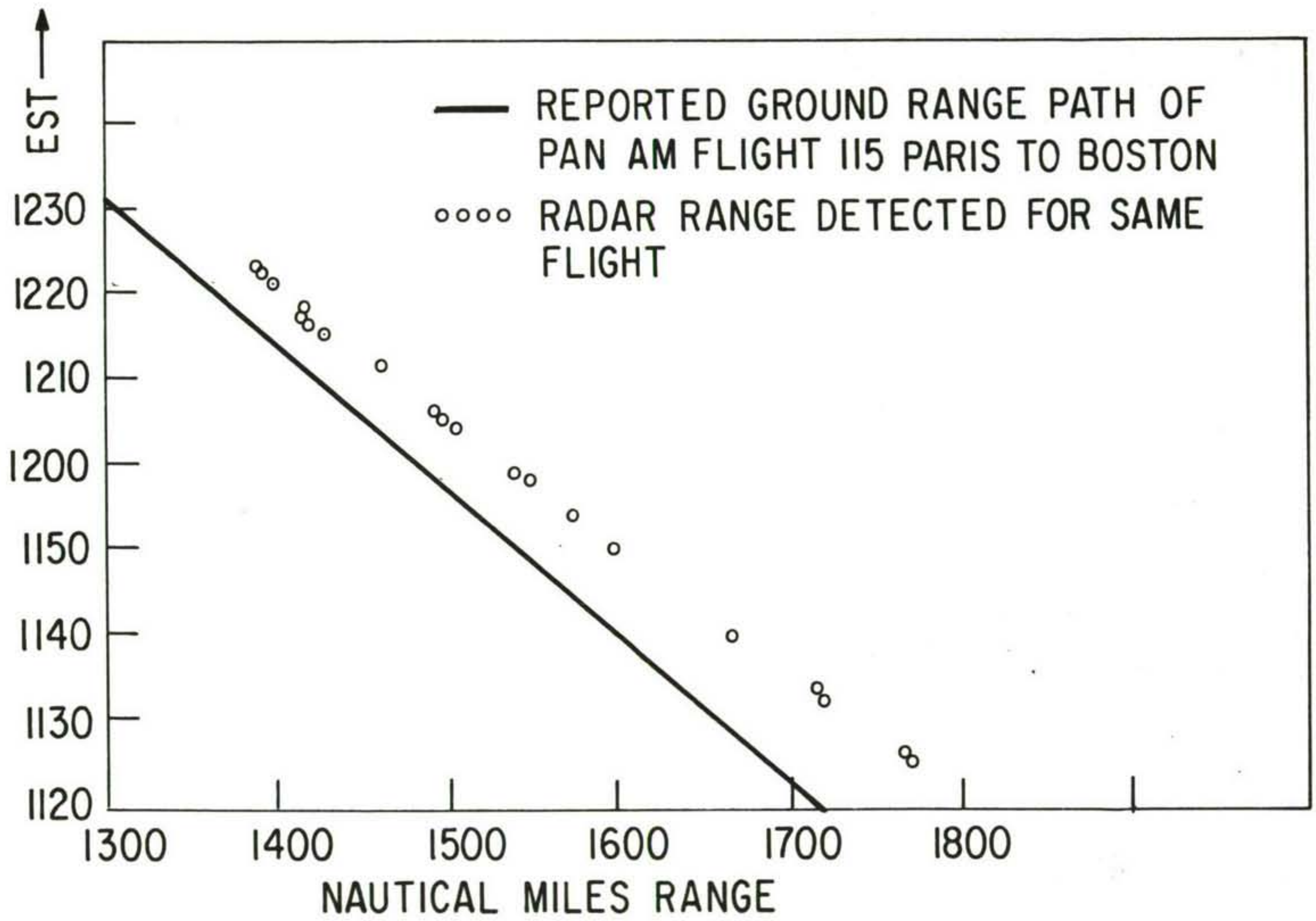


Fig. 2 - Time-range plot for typical track of aircraft. Radar range could have been corrected to ground range. From NRL Report 5898.

[redacted]

The display of missile targets on the doppler-range facility should conform to that shown by Figs. 3 and 4 which are examples of an Atlas out of PMR and AMR respectively. The range gated doppler-time type of display is exampled by Fig. 5 which is the doppler-time display of an Atlas from PMR. Similar displays of Polaris are shown by Figs. 6A and 6B. Figures 7A and 7B are acceleration gate displays as noted by their titles.

GENERAL SITE REQUIREMENTS

The following requirements are considered part of the site needs.

FENCING

The chosen site must be enclosed in an RADC approved chain link type fence with barbed wire top, necessary gates and security lighting.

BUILDINGS

All building structures should be of steel rectangular shape, made in sections fabricated in the U. S. for erection overseas, insulated, some air conditioned, and of a mechanical design which allows good element electrical bonding.

POWER PLANT

The power plant can consist of say four, 1000 kw diesel-driven generators. This plant should be fairly remote from the main station, commissary, etc.

FUEL STORAGE

Above ground fuel storage tanks, the content of which will be replenished by tank truck service, must be of sufficient capacity for the power plant.

SEWAGE DISPOSAL

An adequate waste disposal system must be supplied.

WATER SUPPLY

There are no important surface water sources and site activation would include the drilling and equipping of deep wells.

[redacted]

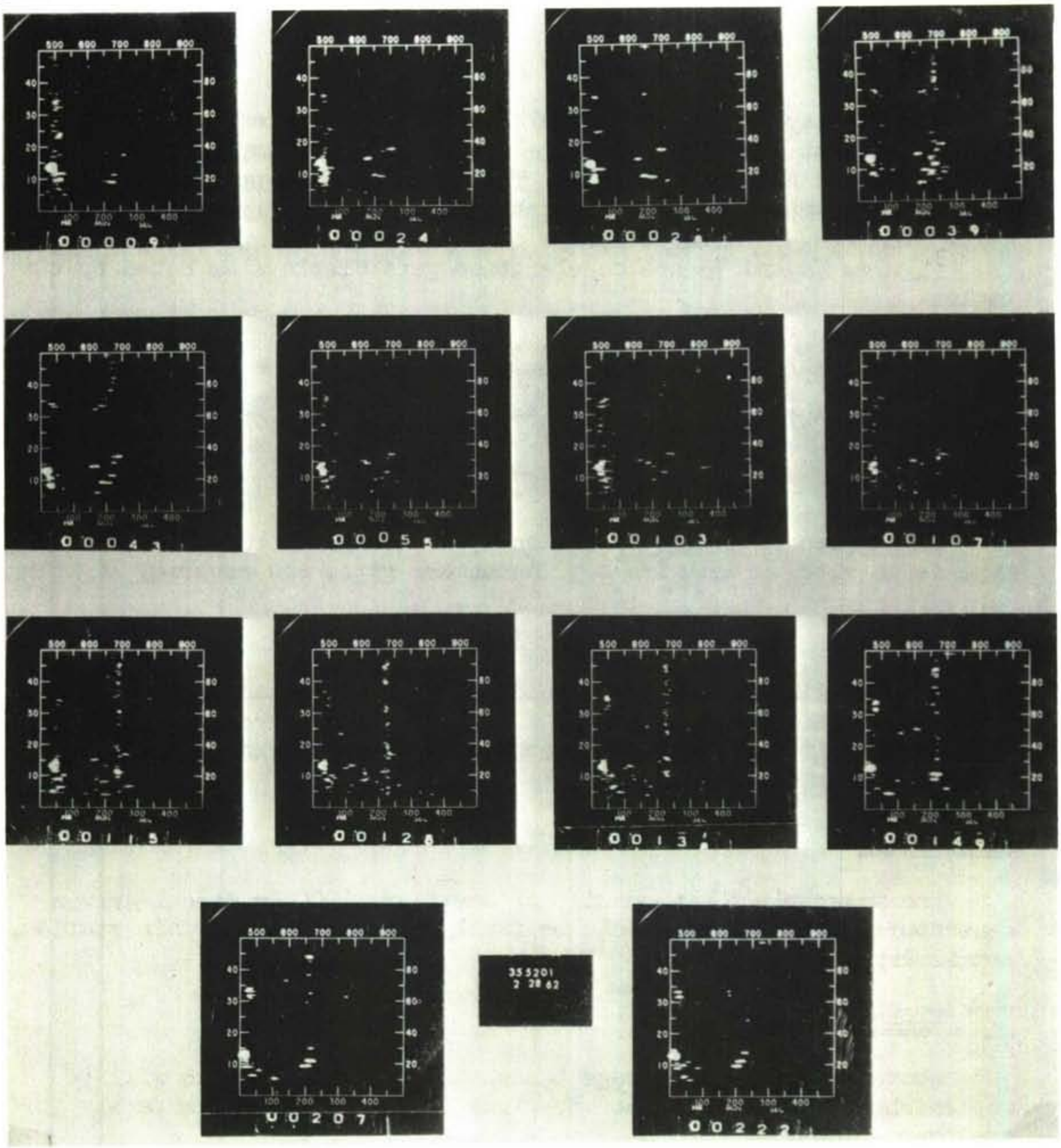


Fig. 3 - Primary display for PMR test 355201

Missile: Atlas E

Frequency: 18.036 Mc

Antenna: Bearing 270^0, Re NRL-CBA, free space gain 11.60B

Launch: T_o 7:14:09 PM EST 2/28/62

Time counter indicates minutes and seconds after T_o

Abscissa range covers 2250 - 2300 naut. mi.

Ordinate: 0 - 45 cps doppler

From NRL Report 5811

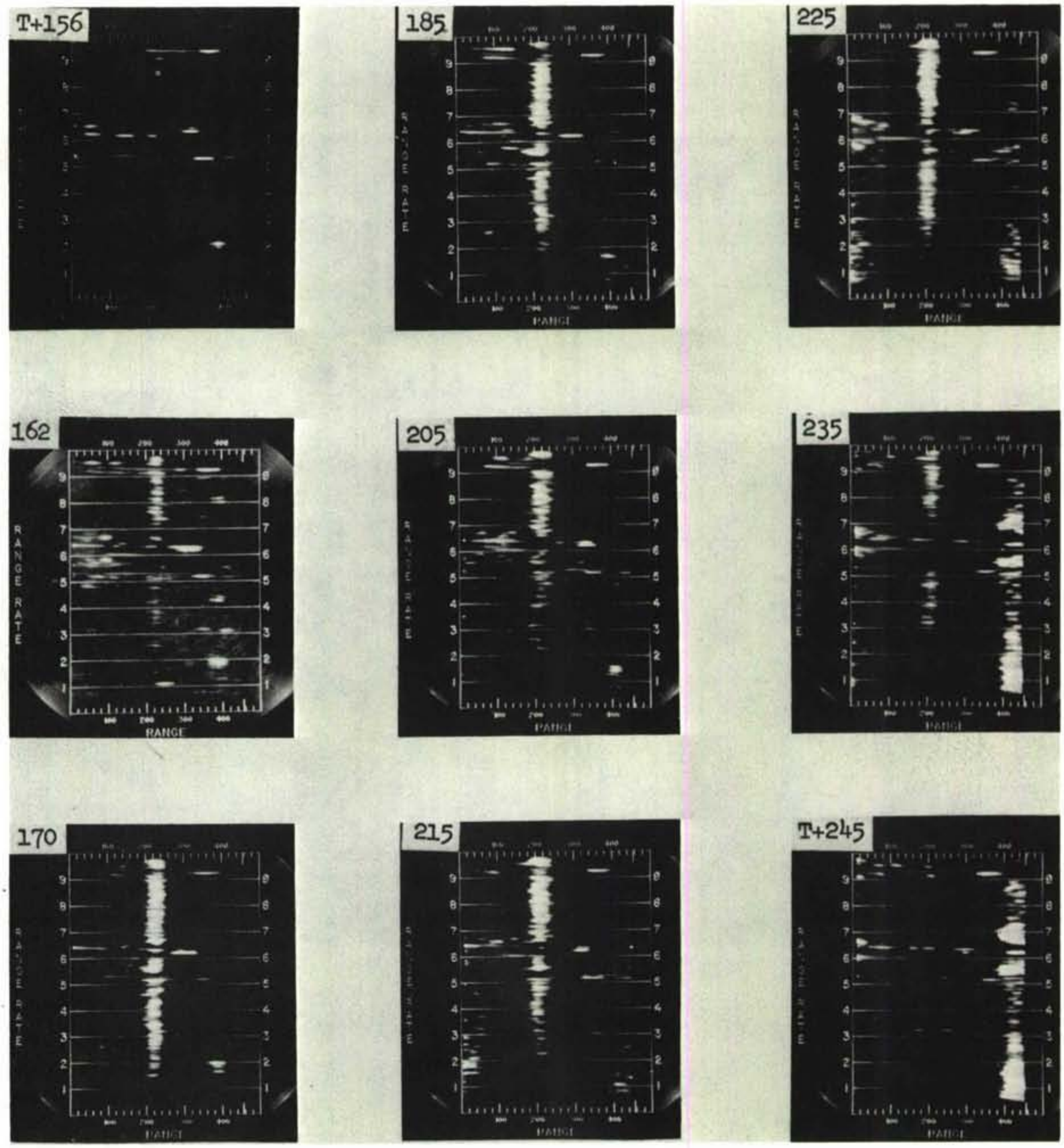


Fig. 4 - Test 5462. Doppler vs range for indicated seconds after launch. Abscissa displays approximately 450 - 900 naut. miles; 200 on scale is about 700 naut. miles. Ordinate displays 0-45 cycles; 0.5 on scale corresponds to zero doppler and 9.5 to 45 cps. Missile evident from T_o+ 156 to T_o+ 235. Spread to right and left of frames T_o+ 215 to T + 245 is ionosphere perturbation. Operation conditions - frequency 16.16 Mc, PRF 90 pps; missile, ATLAS AMR 12/1/62. From NRL Report 1287.

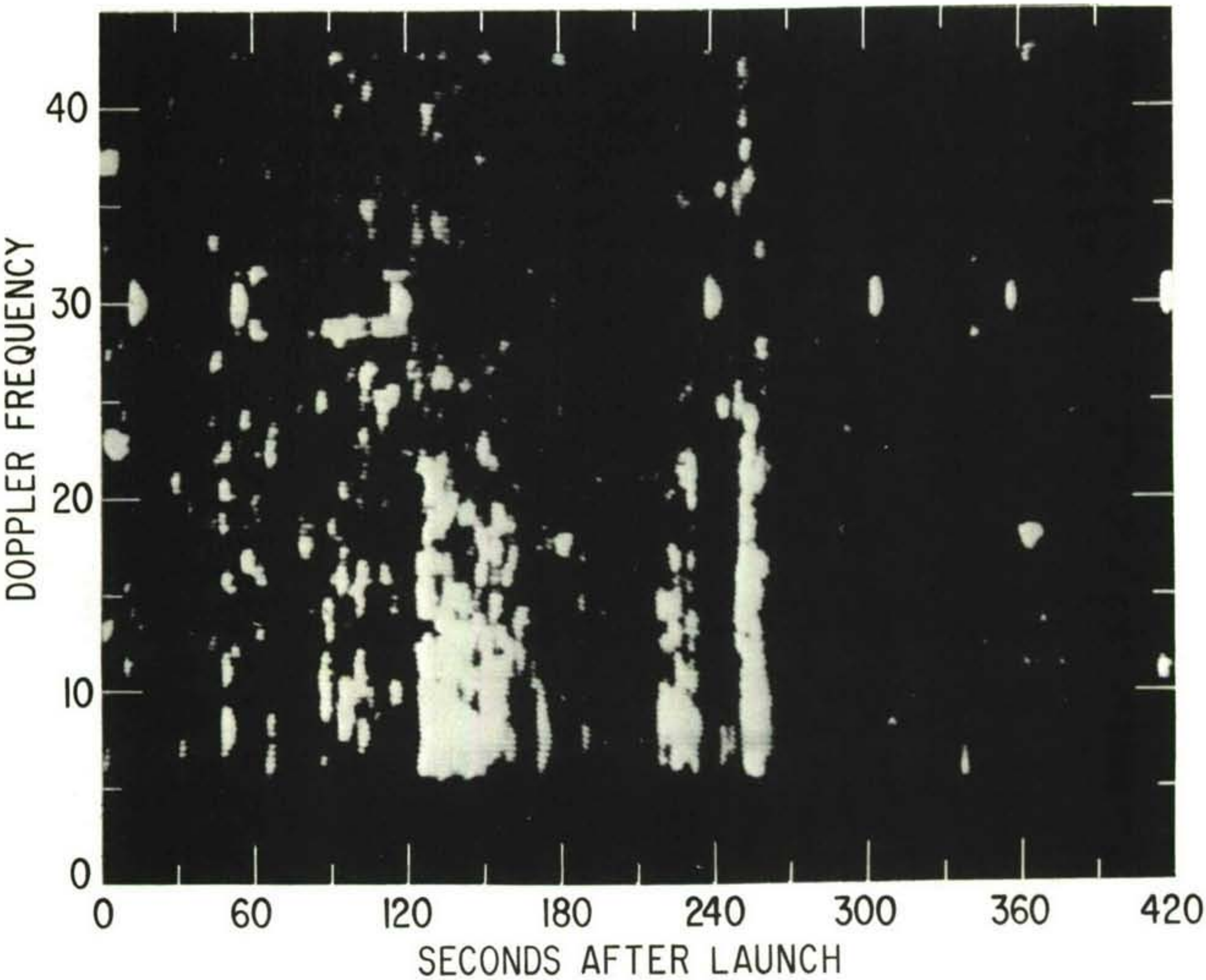


Fig. 5 - PMR test 1618, lift off 1736:49Z, 30 July 1963; look direction 279°, frequency 23.1 Mc, repetition rate 60 pps, 40 mile range gate located just inside 2600 naut. mi. This range gated doppler-time-history readout display was photographed at T_o + 7 minutes. The signature due to booster engine cutoff and jetison can be seen starting at about T_o + 125 seconds and persisting until T_o + 170 seconds. An exhaust boundary reflection comes in weakly before and strongly after T_o + 240 seconds. The short period of exhaust boundary reflections is thought to be due to inadequate illumination.

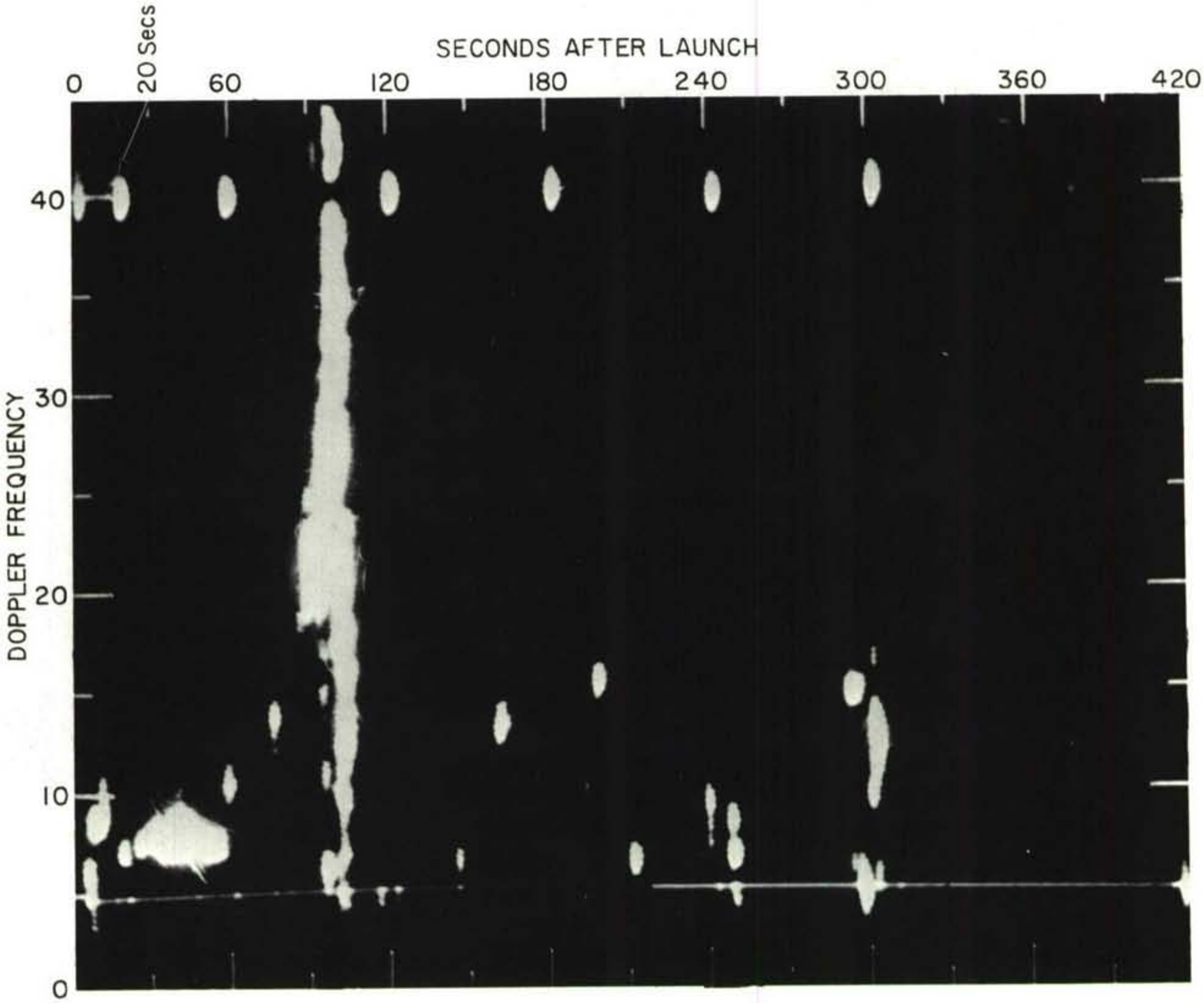


Fig. 6A - AMR test 0238, A-2 Polaris, T_o 16:41:08Z, 2/3/64. A range (1 millisecond) gated doppler-time history from T_o to 7 minutes. This form of presentation is an accumulated display of frequency-time events. Doppler resolution is 1 cps; time resolution about 5 seconds. The missile signature is strongly evident in the one minute - two minute period.

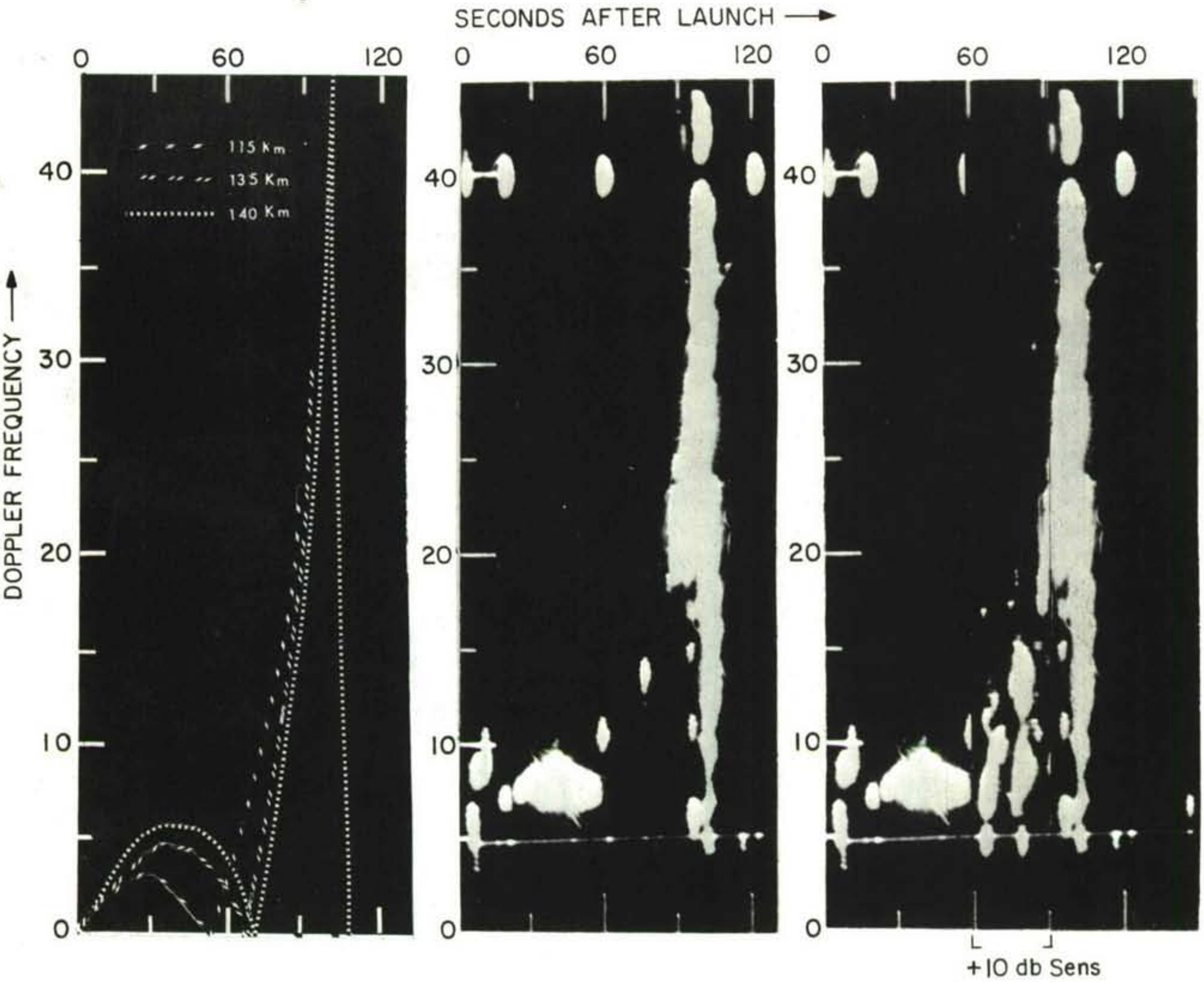


Fig. 6B - AMR test 0238, A2 Polaris, T_0 16:41:08Z, 2/3/64. This figure is in support of Fig. 6A. On the left is shown computed (NRL - CBA - CAPE KENNEDY) doppler-time based on reflections from ionospheric heights of 115, 135, and 140 km. From 0 to 60 seconds the doppler is approach; in the vicinity of 60 seconds doppler goes to zero; and afterwards recedes. Due to a test repetition rate of 90 cps the doppler folds at 45 cps. The center picture is a short section of Fig. 6A showing the real time radar display. The picture on the right was made by rerunning the memory tape with 10 db increase in system sensitivity for time between 60 and 90 seconds to enhance lower amplitude echoes.

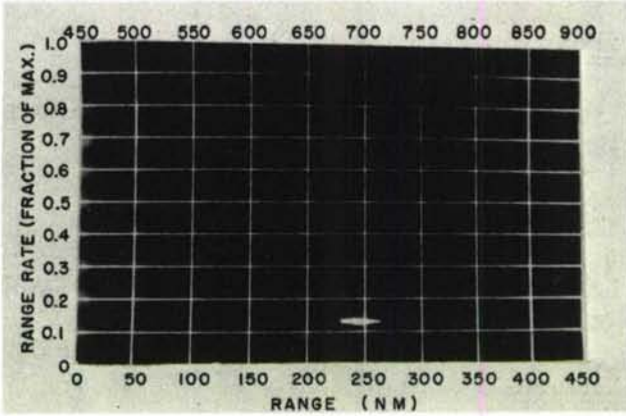


Fig. 7A - Test 0351 Minuteman AMR, 3/13/64. Operating frequency 15.595 Mc. Operation of acceleration gates. Display range rate vs range with compression of the target spectrum into a narrow spike signal. Under these operating conditions one can recover up to 20 db gain over spread displays of range rate vs range such as Fig. 6.

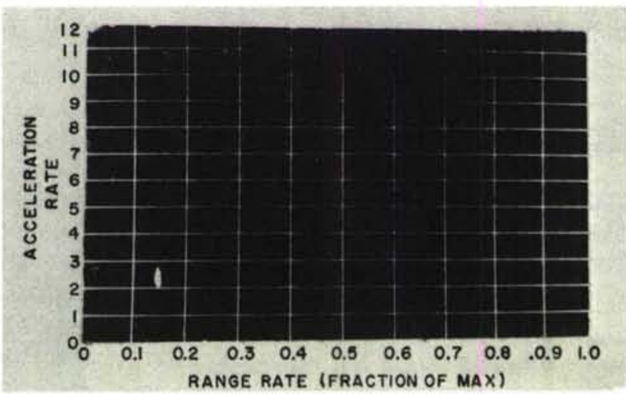


Fig. 7B - Display of acceleration vs range rate of Fig. 7A missile showing compressed target spectrum in range rate

[redacted]

COMMISSARY FACILITIES

A commissary facility must be provided for the normal station complement for 24-hour operation.

COMMUNICATIONS, LOCAL

An adequate telephone and call system must be provided between the key points of the site.

COMMUNICATIONS, EXTERNAL

A microwave link, for approximately a ten-mile haul, must be provided the site.

COOLANT CONSERVATION

Water for coolant must be conserved by recycling.

ROADS

It will be necessary to construct several miles of road from the existing hard surface road to and within the proposed site.

SITE PLAN, STRUCTURES

It will be necessary to devise a site plan within a square, 1.7 to 2 miles on a side, which conserves land as much as possible, but one which shows expert disposition of the antenna, antenna feed lines, power lines, power plant, fuel storage, warehousing, main station, guard houses, communication station, commissary, and sewage disposal plant.

POWER FREQUENCY HUM CONTROL

When the proposed site is activated, one is confronted with a unique, but delightful, situation of a virgin start. The power frequency ground currents which give rise to hum voltages between electronic cabinets, connection cables, etc., because of multiple ground points, will exist solely by the degree of thought placed upon the disposition of power wiring, chassis earthing, etc., in relation to the antenna ground screen. The research MADRE complex at NRL's CBA employed single-sided interconnection cabling and the reduction of 60 cycle hum was a major effort. Perhaps one should entertain balanced or double-sided cabling in critical areas to reduce hum to a negligible amount. More will be emphasized on hum as the system component details unfold.

[redacted]

[redacted]

RF NOISE GENERATION

High power HF installations such as the one under consideration are particularly susceptible to arcing in the antenna structure, building structures, electrical wiring, water and sewage, piping, telephone circuits, air conditioning, etc. All power wiring, piping, etc., should preferably be underground level and where it is necessary to emerge above the ground on the ground screen runs should be shielded and these in very close proximity avoided or else judiciously bonded.

Antenna towers bracing, building construction steel and the antenna structure itself should be of such design as to eliminate R.F. brushing corona, and arcing, since this is a source of R.F. interference, telephone interference, equipment outages, and a fire hazard.

EQUIPMENT TEMPERATURE REQUIREMENTS

Electronic equipment in operation may experience a variation in indoor environmental temperature between 15°C and 32°C. Outdoor operating temperature variations fall between -20°C and 54°C. The latter range is suitable for consideration of the conditions for the nonoperating state of equipment in storage whereas in transport the temperature range to consider is -54°C to +70°C.

OPERATION AND MEASUREMENT FACILITY

The site must provide operation and suitable measurement facilities in the form of two 120 db screen rooms: one to house all system components not a part of the transmitting function; the other, of smaller size, where components can be tested and repaired. The latter facility should allow low-level work while the station is in operation. NRL Report 3578 or Department of Commerce Publication PB100752 should be consulted for guidance.

RADAR SYSTEM PRELIMINARY REQUIREMENTS

Figure 8 is a block diagram of a "for instance" radar which indicates one known means of performing the task; additions, changes, etc., are invited if they foster a more complete fulfillment of the mission requirements.

The diagram assumes a plurality of antenna elements along with transmitter(s), duplexer(s), and beam steering matrices with terminals which include two receiving channels. One purpose of the duplication is to provide amplitude comparison for azimuth angle of arrival beam location.

The receiving channels indicate a means of taking a signal, of any input frequency, and subjecting it to fixed frequency filtering. The

[redacted]

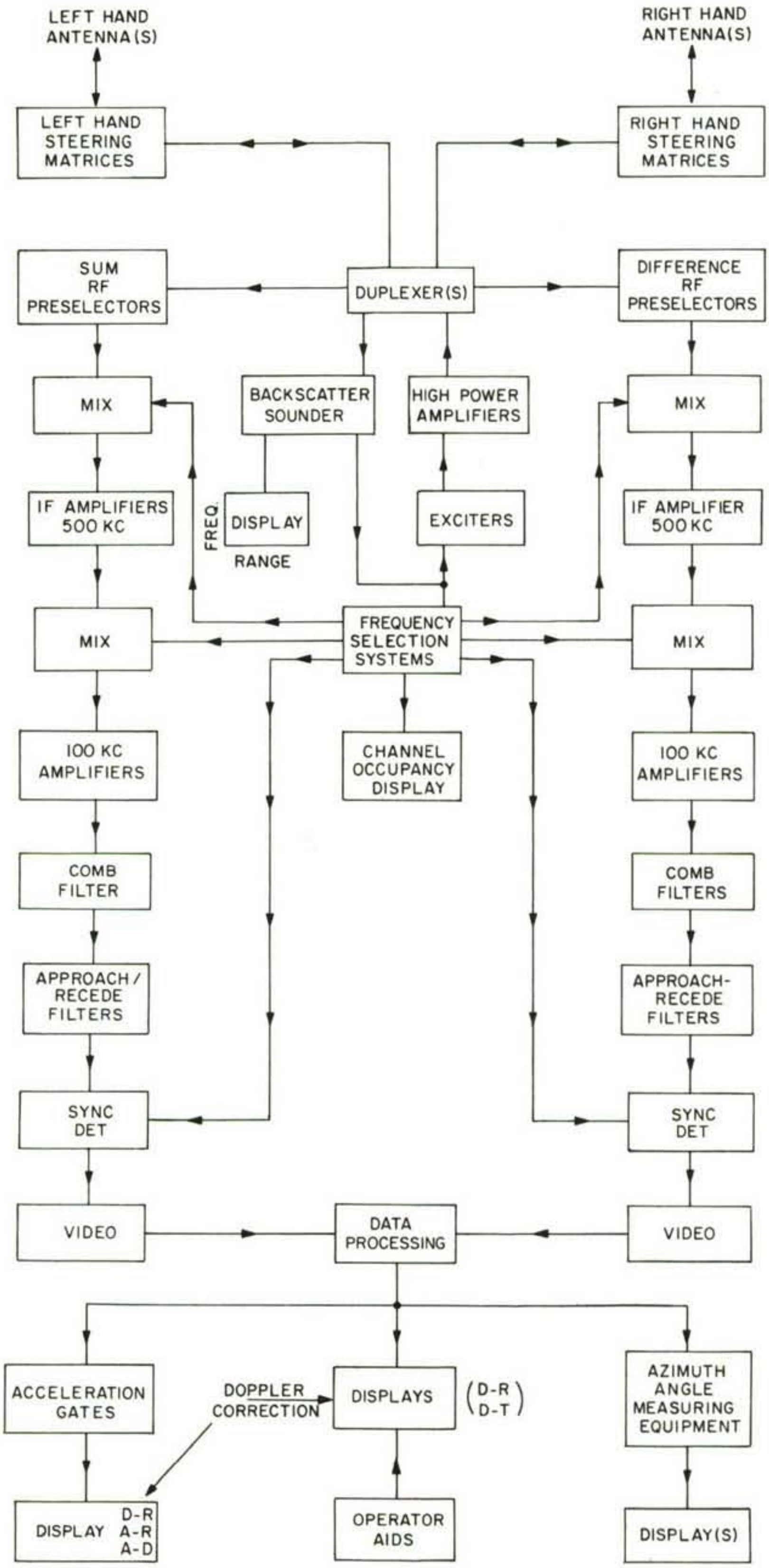


Fig. 8 - Block diagram of generalized system

output of the latter enters a 60 db, or better, dynamic range signal processor, which in turn is reprocessed for display means. Memory blocks indicate means to record the receiver outputs as well as the inputs to the displays. The main displays would include presentation of doppler-range, doppler-time, skip range, range depth of illumination, etc. These displays are also shown to be associated with operator aids. These could include a small computer, track memory, statistics storage, data coding for transmission to remote location, etc., as the data rate of the mission or its growth requires. There is also a path out of data processing to the acceleration gate block, which contains separate displays. This latter feature is indicated as ultimate, especially for small, low-altitude, far-range missiles. A compatible inclusion of this facility is considered part of the study.

Returning to the same receiving channels it is noted that a look-through-for-idle channel and transmit-frequency call-up is provided which feeds the receiver system as well as providing input to the driver to the power amplifier(s).

The diagram also shows duplexer(s) connected to power amplifier(s) which are in turn driven by the driver(s) which are fed from the control frequency selection system.

The diagram shows some doppler compensation to the displays such that their calibration is meaningful when nominal frequencies are changed and when open-channel operation frequency shifting is accomplished in the vicinity of the nominal frequencies.

Finally, it is noted that there is an ionosphere and backscatter sounder block which must provide display of the skip range, range depth of illumination and ionospheric layer heights at the transmitter, the latter often useful in converting radar range to ground range.

With Fig. 8 as a background, the system components are considered subsequently in more detail.

ANTENNA(S)

GENERAL AIMS

The general aim is to obtain one-hop sector terrain illumination in the 500 to 2000 nautical mile range from the antenna site. This aim suggests an outside operating frequency limit of 4 to 40 Mc for the particular site and look directions under consideration and such a design accomplishment is considered an ideal goal. Due to the dictates of nature and some specific antenna form in mind, some performance sacrifice in range coverage may be considered at the range extremes which suggests two secondary frequency ranges, i.e., 4 to 30 Mc and 6 to 40 Mc. The first of these ranges places more firmness on the

500 to 700 nautical mile figure with some relaxation in time use reliability of the 1800 to 2000 nautical mile portion of the range. The second range places firmness in the time use reliability of the 2000 nautical mile figure and some relaxation in the time use reliability of the 500 to 700 nautical mile portion of the ideal range. Both of these ranges are considered excellent with respect to the ideal with a preference on the 6 to 40 Mc range due to the relative ease and relatively low cost of providing the upper ten megacycles in some antenna designs. The lower two megacycles of the 4-30 Mc range is no doubt costly, whatever the design form. The prospective vendor is encouraged to consider these lower two megacycles as an addition to a 6-40 Mc design even at some sacrifice of efficiency by the use of loaded elements, for example, to curtail height and general size of this portion of the antenna. No appreciable loss of efficiency is entertained in the range 30 to 40 Mc. Whatever state of the art frequency range the prospective vendor proposes, the antenna must generate efficiently over at least a 6 to 30 Mc band where a simultaneous fast fall off in performance below or above these figures would result in only a tolerable design.

FREQUENCY-CHANGE TIME

The time required to change the frequency of operation shall be less than 5 milliseconds. If the proposed frequency span is broken up into several bands, the change from one band to another may exceed 5 milliseconds but should not be greater than 30 seconds. Simultaneous operation on any three frequencies shall be possible.

GAIN

Constant gain over a proposed operating frequency band is ideal and some designs may achieve substantially this characteristic. It is desired to achieve a gain (relative to an isotrope) of 20 to 23 db over the operating band. This figure does not include 6 db main lobe contribution due to a perfect ground. With some designs these figures are not realistic and a variation of 17 to 23 db would be considered if the proposed design indicates features of superiority in other areas.

STEERING

It is desired to steer the antenna beam center in a horizontal plane over an angle of 140°, though if the design provides 150° or even 160° degrees without excessive additional cost, the design will be favorably received. Smooth azimuthal progression of the beam is ideal, but step movement is acceptable. The time required to change the beam position should be as small as possible but in no event should it exceed 5 milliseconds.

BEAM WIDTH

A constant beamwidth over the operating band is ideal. The desired beamwidth in the horizontal plane is nominally 10° although a variation between 5° and 15° is acceptable.

SIDE LOBES

It would be ideal to have all the side lobes down at least 25 db from the main beam, but there is considerable variation in designs and a limit of 20 db might be acceptable. This requirement does not apply above 40° elevation.

BACK LOBES

The back lobes should be at least 20 db down from the main lobe.

VERTICAL BEAM COVERAGE

It would be ideal to achieve vertical coverage from 0° to 40° above the horizon, however, the range from 2° to about 30° may be considered acceptable where the effective gain within this range is at least 25 db. The extended high frequency (30-40 Mc) should be effective at the small angles and the extended low frequency range (4-6 Mc) should be effective at the high angles if provided.

R.F. POWER HANDLING

It is desired that the antenna(s) which form the beam be capable of main feed input power of 600 kw average and 10 megawatts peak, with feed lines, stubs, etc., capable of resonant rises and encountered VSWR increases without breakdown when operated in area weather environment.

MECHANICAL FEATURES

Whatever the design, mechanical rigidity, or vibration frequency cut off by mass controlled elements and members, the effective mechanical rigidity shall be determined by the system requirements for spurious modulation. Any single modulation component above 2 cycles per second produced by mechanical movement within the antenna or its structure shall not exceed one milliwatt of radiated power, that is, these components shall be at least 83 db down.

POLARIZATION

The polarization of the antenna is not specified but combinations of vertical and horizontal polarization are acceptable.

INPUT IMPEDANCE

The input impedance(s) of the antenna shall be compatible with the transmitter(s) and duplexer(s).

BEAM OPERATION

The antenna should be capable of simultaneous beam and/or azimuth only monopulse operation to provide $\pm$ 2^0 bearing locations.

GROUND SCREEN

The proposed antenna will require an adequate ground screen to reduce losses, provide a ground reference for signal processing, and provide the desired lobe pattern performance. The prospective contractor should stipulate an adequate ground screen and if foreshortened a measure of the effectiveness stated.

TOWER LIGHTING

Antenna structures above a height of fifty feet must be considered to require standard lighting.

SURVIVAL

The antenna structures which are entertained are those of a design which would survive with moderate ice loading in a 100 MPH wind.

ANTENNA AUXILIARIES

All transmission lines, feed lines, stubs, variable phases, etc., are considered part of the antenna system except where they are rightly part of the duplexer(s). Sliding contacts and movable capacitors both exhibited limited life and their use should be avoided wherever possible. See the transmitter(s) section for further details.

VSWR

The antenna VSWR should be as low as possible as a function of frequency and be compatible with the load requirements of the broadband transmitter(s) so as to exhibit minimum loss in feed lines and reduce the tendency for feed line flashover.

VERTICAL SOUNDING ANTENNA

A standard vertical ionosphere sounding antenna will be required within the site confines.

TRANSMITTER REQUIREMENTS

POWER REQUIREMENTS

The transmitter requirement best suited to the needs of fulfilling the mission will fall somewhere between one to three large high power units and a multiplicity of lower power units. The aggregate is a maximum of 200 kw (10 megawatts peak) on an operating frequency. It is more economical to transmit on one operation frequency, receive and display the data and then shift to another operation frequency and repeat the performance cycle. As mentioned previously transmission on three consecutive frequencies could demand 600 kw average power. Also it would be preferable to provide the full 600 kw at one frequency when desired.

Reference is now made to the antenna portion of this document where it is stated that the power handling desires could run as high as 600 kw average, 10 megawatts peak. If this capacity is available, then consecutive transmission of two or three frequencies would allow increased data rate. There are obvious cost trade offs here with data rate, growth potential, etc., and these alternatives should be considered. If the lower data rate (200 kw 10 megawatt peak) is chosen the design should readily accommodate rf power additions at a later date when a faster data rate is desirable.

GENERAL WIDEBAND REQUIREMENTS

With a wide band antenna and fast acting associated beam and beam switching mechanisms in mind, the objective is to power such a radiating system with wide-band amplifiers of the distributed type or fast switching band-tuned type. The amplifying equipment is to include all power supplies, heat exchangers, and other accessories for operation.

FREQUENCY RANGE

The frequency range(s) of the transmitter power amplifier(s) shall be consistent with that made possible by the antenna frequency range requirement.

BANDWIDTH

The bandwidth shall be consistent with that made possible by the antenna frequency range requirement.

TUNABILITY

Full frequency range band-pass or switchable sub-bandpass for harmonic suppression.

CLASS

The amplifier(s) must operate linearly over a wide range of input signal amplitude.

OUTPUT POWER

A single unit amplifier must be continuously variable from 2 kw to 200 kw average power. Where multiple units are contemplated the low power sum shall be 2 kw and the high power sum 200 kw average. Adequate shielding of the units must be provided and rf "power on" flashing warning lights arranged at strategic poinst inside and outside the main station buildings.

PEAK POWER

The amplifier(s) shall be capable of a peak pulse power output of 10 megawatts.

POWER GAIN

The power gain of the amplifier(s) will be approximately 20 db, ± 1 db, but must be consistent with the drivers supplied.

DUTY FACTOR

The duty factor will vary for pulse periods of 20 to 400 pps with corresponding pulse lengths from 1000 μs down to 100 μs. In addition, three frequencies may be transmitted consecutively within 6 milliseconds.

OUTPUT TERMINAL

The output should be coaxial, 50 ohms. If multiple transmitters are contemplated impedance shall be compatible with the proposed system of multiple unit feed.

PULSE SHAPE

The pulse to be amplified is of cosine squared shape or a shape generated by bandwidth limiting.

TUBE LIFE

The power tube life must be at least 1000 hours.

METERING AND SAFETY

All circuits shall be adequately metered, rf forward and reverse power monitored and adequate safety devices and lock-outs provided.

DARK NOISE

The aggregate noise output power between pulses shall preferably not exceed 10^{-13} watts, but in any case in combination with the duplexer(s) it should not degrade the receiver performance. The dark noise is measured with normal voltages applied but without rf excitation. With the amplifier(s) connected to a matched load, without the duplexer, the dark noise is measured across the load with a device having a bandwidth of 5 kc. Every reasonable effort should be made to better the dark noise limit mentioned above and tubes with bombardment heated cathodes should be avoided.

PHASE JITTER, PULSE AMPLITUDE MODULATION

Phase jitter from any cause can defeat the mission for the system. Undesired modulation components must be as low as the state of the art permits, but in no case shall any single component from the aggregate be greater than 1 milliwatt average.

SPURIOUS FREQUENCIES AND PARASITIC SUPPRESSION

The amplifier(s) must demonstrate the absence of rf output in the absence of rf drive. They must also show an absence of spurious output under any degree of input drive.

POWER OUTPUT

Variable from several kilowatts to full power.

POWER FREQUENCY HUM

Hum at power frequency and multiples thereof are in the useful doppler frequency range of the system. Every means should be used to suppress such emission by excellent filtering and filament heating with direct current.

VERTICAL SOUNDER

A standard vertical ionosphere sounder must be provided.

EXCITER(S) CHARACTERISTICS

The exciter(s) characteristics are, except for power levels, included in those of the power amplifier(s).

(a) Pulse shape - the pulse shape shall be maintained at all drive levels so that side frequencies beyond 5 kc from an emission frequency will be less than the carrier power by 20 db or more. The pulse shape reproducibility for the integration period must be ideally exact.

(b) Pulse length - the pulse length is measured between the 10% voltage points and conforms with that stated for the power amplifier(s).

(c) Power output variation - consistent with the specification for the power amplifier(s).

DUPLEXER(S)

The purpose of this unit(s) is to allow broadband, common and efficient use of the radiating system by both the transmitter(s) and receiver(s). Where the transmitter is in one or a few units the duplexer(s) must handle large power. Where the system power is distributed in multiple transmitters, multiple switches of lower power handling capacity may be used and multiple receiver preamplifiers may feed the main receiver(s).

(a) TR function - isolate the receivers from the transmission line(s) during the transmit period and assure delivery of substantially all of the transmitter(s) output(s) to the radiating elements. In this mode the receiver isolation should be more than 60 db.

(b) ATR function - isolate the transmitter(s) from the receiver(s) during the receive periods so that maximum received power is delivered to the receiver(s) and noise from the transmitter minimized.

(c) Recovery time - if solid state switching devices are employed the recovery time can be about 15 μs. NRL has successfully operated solid state, liquid cooled switches between 13.5 and 30 Mc on 9" line at 100 kw average power level. NRL visualizes no trouble going downward in frequency or upward if the line size is smaller. Information on solid state duplexing is obtainable from NRL.

[redacted]

MASTER FREQUENCY SELECTOR AND PROGRAMMER

The Master Frequency Selector and Programmer must cover the selected frequency range (say from 4 megacycles to 40 megacycles in 36 one-megacycle steps). It will display a one-megacycle bandwidth in this range and allow identification of unused channels. It will select the open channels in a random manner at any preset rate from one every three minutes to 60 selections per second. It will convert the selected frequency into appropriate command signals for a frequency synthesizer, such as Hewlett Packard 5100A, and the electrically tuned or selected stages of an external receiver.

To accomplish this the arrangement outlined in Fig. 9 is proposed. An rf preselector with a one-megacycle bandwidth feeding a mixer with a noise figure better than 12 db and a dynamic range of 100 db is recommended. The local oscillator will be a switch-tuned internal oscillator with provision for an external source such as a Hewlett Packard 5100A.

The output of the mixer feeds an intermediate frequency amplifier with 1-megacycle bandwidth at a suitable center frequency. This amplifier feeds a comb of 200 crystal filters of 5-kilocycle bandwidth with the adjacent filters matching at the 3 db points. This forms 200 channels; each channel is outlined below.

The individual channels feed an amplitude detector followed by a variable bandwidth low pass filter, the bandwidth of this filter to be variable from 60 cycles to 0.1 cycles. This filter feeds a threshold detector with the threshold capable of being varied from 1 millivolt to 1 microvolt at the input to the system. This threshold detector feeds an And gate which is fed by a digital designating system. This gate feeds another And gate which is fed by an analogue to digital converter which is capable of 12,000 8-bit conversions per second. This converter is fed by a noise generator with a bandwidth of at least 100 kc. This arrangement shall have an equal probability of selection of any of the 200 channels.

The digital designator will feed each And gate with a set of binary digits which will designate its position in the 1-megacycle bandwidth. The digital designator must be easily programmed to designate any channel as a zero channel and thus prevent it from being selected.

The output of the above system is fed to a gate which also receives a select command from a command module. The output is fed to a hold circuit which receives a reset command from the command module at the same time the select command is generated. This hold gate stores the first frequency signal it receives after a reset command and sends it to a converter which converts the digital signal into suitable form to program a HP5100A frequency synthesizer. The command module must be

[redacted]

[redacted]

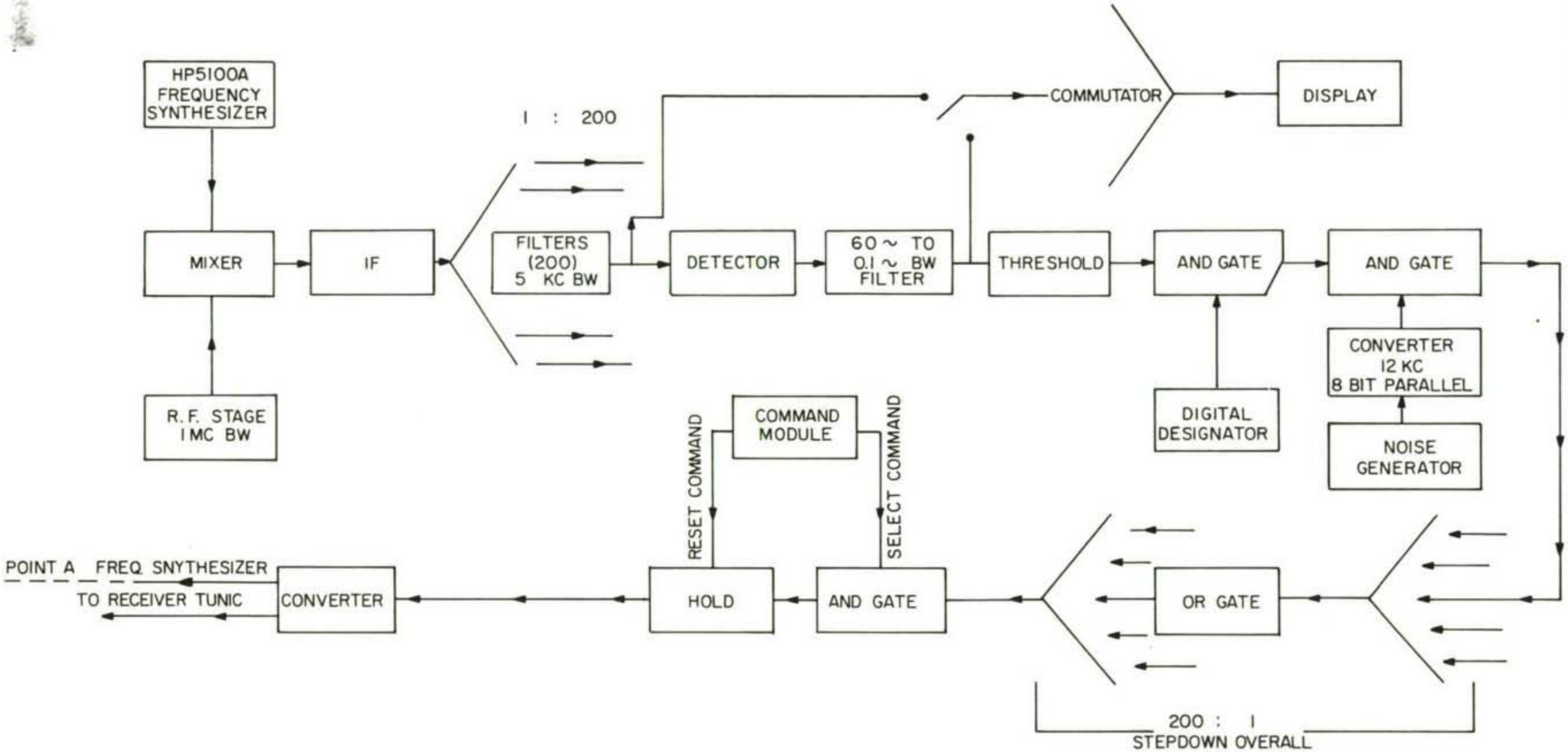


Fig. 9 - Master frequency selector and programmer

[redacted]

capable of being easily programmed to produce a select command at any rate from one every three minutes to 60 commands a second. An auxiliary commutator and display system shall be provided capable of displaying either the output of the crystal filters or the output of the low-pass filters. The cathode ray tube display may have a linear characteristic or a logarithmic characteristic capable of displaying 1 microvolt to 1 millivolt at the input to the system.

It is noted that the provisions of this frequency selection function also permit operation on assigned frequencies if desired.

Figure 9A is that part of the frequency generator system under the control of the frequency selector and programmer which provides transmit and receiver injection frequencies. The input to the frequency select command unit, Fig. 9A, is fed from the converter, Fig. 9, (Point A).

RECEIVER CHARACTERISTICS

Receiver and signal preprocessing equipment for HF radar operation. have restrictions which preclude the use of some common radar receiver practices such as AGC because their use would degrade performance. The design of the receiver must encompass several basic factors.

(a) Dynamic range - First, and all important, the dynamic range must be sufficient to permit linear amplification of microvolt signals in the presence of millivolts of clutter due to (a) backscatter returns from the large illuminated area and (b) other spectrum users within or adjacent to the pass band of the receiver. A dynamic range of 120 db linear to ± 1 db is desirable.

(b) Frequency range - The tunable frequency range must be compatible with the range envisioned for the transmitter and antenna components.

(c) Design and shielding - Extreme care must be exercised in the receiver circuit and layout design to employ precision made, high quality parts to eliminate any regeneration or parasitic oscillations, since such effects produce nonlinear amplification, spurious frequencies, undesired overloading, change in bandwidth with gain setting, unstable gain and tuning and, in general, undesirable results.

NRL has constructed receivers with adequate shielding between stages and filtering of necessary interstage connections so that there is no indication of regeneration or parasitic frequency generation. Proper shielding and filtering also reduce susceptibility to interference as it insures that only signals introduced at the receiver

[redacted]

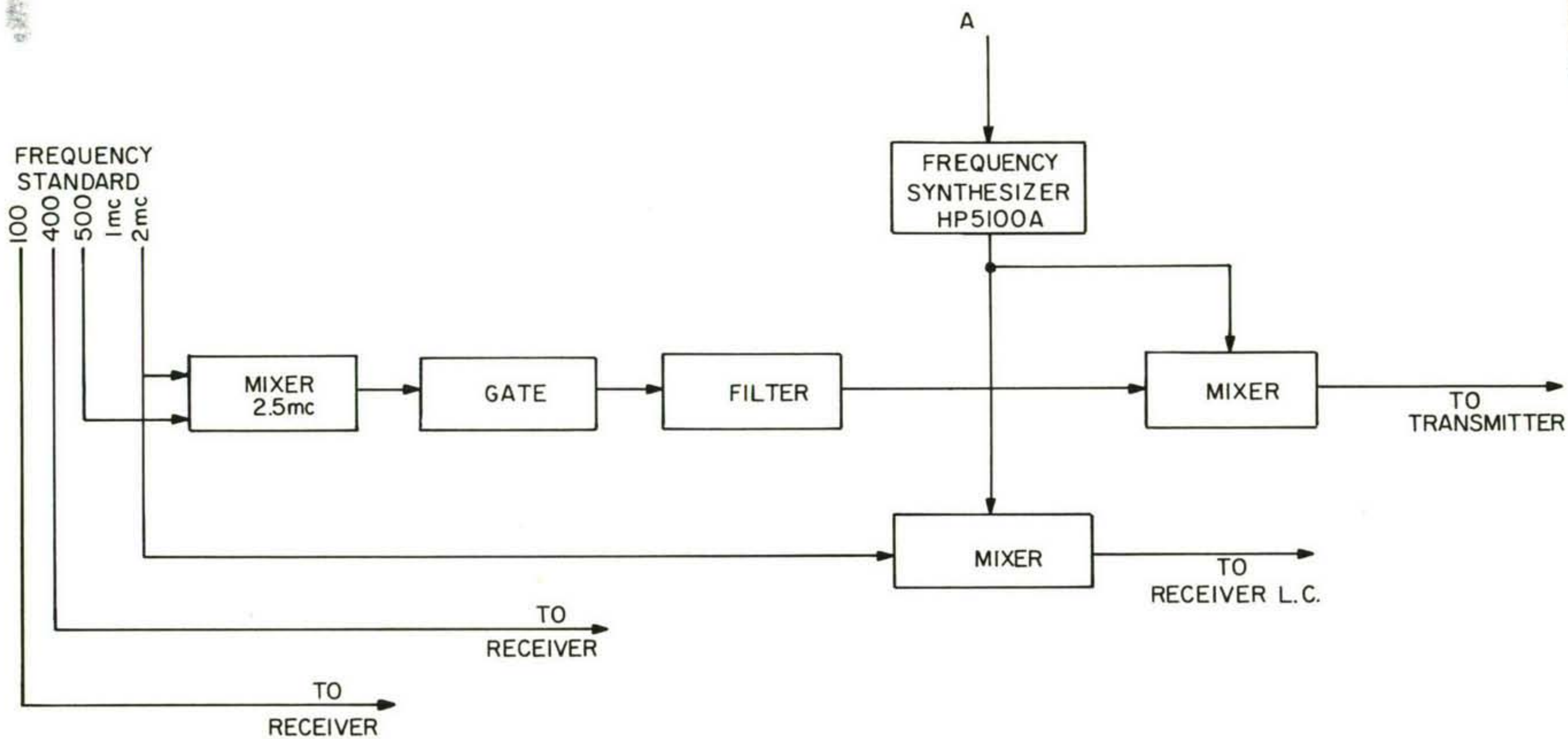


Fig. 9A - Unit fed by master frequency selector and programmer to provide transmit and receiver LO's, etc.

[redacted]

terminals are subject to processing. NRL design also includes an overshield to enclose the complete receiver with the precaution of filters in <u>all</u> powering leads. This procedure is perfected when there is no output from the receiver with the receiver tuned to the transmitter but with the input to the receiver capped.

(d) <u>Power frequency hum</u> - The receiver must not introduce additional frequencies on its output due to power supplies and improper filament heating. Well-filtered and regulated plate supplies and well-filtered d-c filament supplies are required.

(e) <u>Gating and blocking</u> - Duplexers are not perfect and there is some receiver input when the transmitter is on. The time and length of the gate pulse must be adjustable and appropriate for no receiver output during the transmit time. This gating circuitry must not introduce spurious display responses at the output of the system. Signal returns from meteors are often very large and overload the receiver but sensitivity must be restored in minimum microseconds following such overload.

(f) <u>Receiver block diagram</u> - Figure 10 is a simplified block diagram of the electronic equipment to perform the task. It consists of a multi-stage preamplifier(s) at signal frequency followed by a first mixer which is local oscillator fed from a receiver LO terminal Fig. 9A to provide a 500-kc i-f to an i-f amplifier, the output of which is subject to further conversion. This 500-kc and another local oscillator injection of 400-kc from an output of Fig. 9A are mixed to produce 100-kc which is suitably amplified. The amplified 100-kc is clutter filtered and fed to the approach-recede target separation filters which in turn feed synchronous detectors. Let us consider the sub-components.

(g) <u>RF (Preselection) Amplifier</u>

(1) <u>Tunable</u> over the band (NRL has used two stage, three tuned circuits)

(2) <u>Bandwidth</u> - 50 to 100 kc

(3) <u>Signal level</u> - linear, $\frac{1}{4}$ microvolt to 50 millivolts

(4) <u>Noise figure</u> - 6 db

(5) <u>Normal input</u> - 10 to 50 millivolts, peak to peak

(h) <u>First Mixer</u>

(1) Conventional type to operate linearly with up to one volt signal input

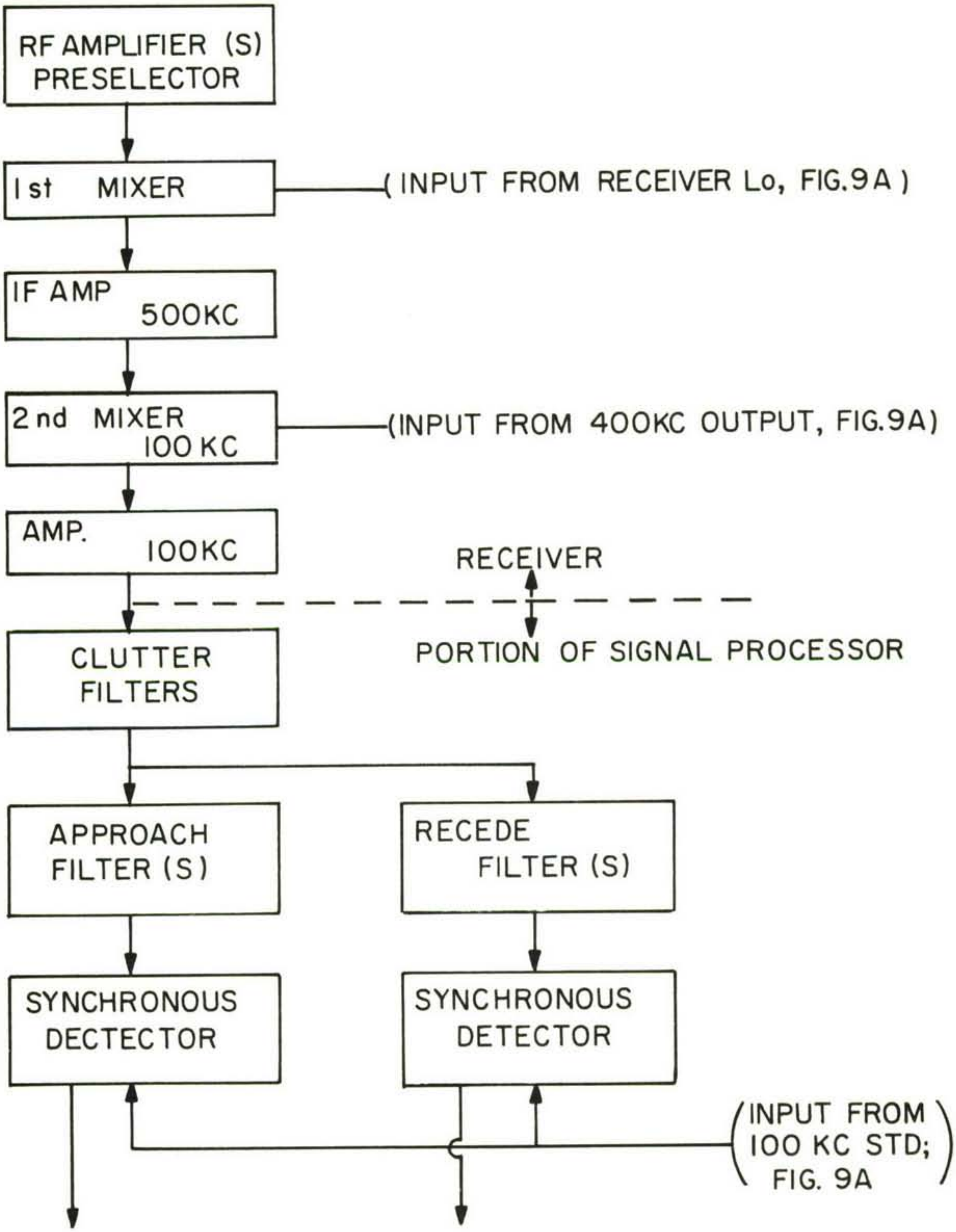


Fig. 10 - Block diagram of receiver including portions of the signal processor

(i) <u>500-KC I-F</u>

(1) Conventional tuned circuit type

(2) Bandwidth - 4 kc

(3) Voltage gain - ≅ 2500

(4) Output - 10 volts across 100 ohms

(j) <u>Second Mixer</u>

(1) Conventional circuitry with special effort to eliminate production of spurious frequencies. In this mixer one strives for a low noise level because the S/N level in this mixer determines in the main the dynamic range achieved.

(k) <u>100-KC Amplifier</u>

(1) Conventional circuitry

(2) Bandwidth - 4 kc

(3) Input signal level - 50 millivolts to 10 volts RMS

(l) <u>Comb filters and approach-recede filters</u> - These filters are treated subsequently as separate items.

(m) <u>Synchronous detector</u> - The outputs of the approach-recede filters feed synchronous detectors. The inputs to the synchronous detectors consist of the desired signal, unrejected backscatter, plus all components produced by interfering signals. Neglecting the interfering signals, these 100-kc signals contain the spectrum of the target return signals which differ from the original signal frequency spectrum by the doppler shift. The amplitude of the desired signals at this point is of the order of 2 millivolts or less. These signals must be converted to the audio frequency band by product detection means. The unit is a form of balanced mixer where the approach-recede filter output is mixed with 100-kc. The output of the mixer is passed through a suitable low-pass filter and an audio spectrum (0 - 2 kc) results.

Considerations of linearity and hum-free operation are of greatest importance in the synchronous detector. NRL has employed some with a total harmonic and noise output 60 db below the desired signal. Noise output in the absence of input signal is of the order of a few hundred microvolts. A synchronous detector is sensitive to both amplitude and frequency modulation and both forms of modulation by power line frequency and its multiples are to be avoided.

[redacted]

(n) Target simulation - Means must be provided to inject known signals into the receiver input so as to provide a standard simulated target for received signal comparison purposes. NRL has employed a method which has proved satisfactory and this information is available.

QUARTZ CRYSTAL COMB REJECTION FILTERS

A comb rejection filter is required to remove high amplitude ground backscatter components from the received radar signal. NRL Report No. 4976 shows that backscatter is confined within a bandwidth of a few cycles as shown in NRL Report 4976. Experience since then has proved that backscatter can be successfully removed with rejection filters, while retaining for normal processing all signals except those with (very low) doppler frequencies which occur within the rejection notch.

The return radar pulse signal consists of a carrier frequency plus as many sideband frequencies (spaced from the carrier by multiples of the pulse repetition frequency) as are necessary to define the pulse shape. This entire spectrum will be offset from the transmitted frequency by the doppler shift produced by a moving target. Backscatter components occur a few cycles in bandwidth centered on each of the zero doppler sideband frequencies. A rejection notch filter is required at each of the zero doppler spectral components that fall within the bandwidth required to pass the pulse.

Filtering will be performed at an intermediate frequency of 100 kc with a composite filter consisting of a comb of quartz crystal rejection filters combined with an overall passband filter. The specific i-f has been chosen so that quartz crystals may be obtained with the required frequency stability and "Q" to fulfill the filter requirements. The exact center frequency is obtained by conversion using a reference frequency coherent with other frequencies in the radar system. A separate and completely independent composite comb filter is required for each of three pulse repetition frequencies, which are: 161.2903, 80.6451, and 40.3225 cps.

The bandpass filter at each prf shall have an overall characteristic capable of passing the i-f pulse. The overall response shall be made up of two sections of approximately equal characteristics: one section shall precede the rejection notches, the other section shall follow them. For the 161.2903 cps prf the response within the passband of ± 2.2 kc from 100 kc shall not vary more than 3 db. The attenuation must exceed 70 db for all frequencies beyond ± 4.9 kc from the 100 kc carrier. At a prf of 80.6451 cps the 3-db range will extend ± 1.1 kc from 100 kc and the attenuation will be in excess of 70 db for frequencies more than ± 2.4 kc from the carrier. At 40.3225 cps the 3-db bandwidth extends to at least ± 0.55 kc from the carrier and the attenuation is in excess of 70 db for frequencies more than ± 1.22 kc from the carrier.

[redacted]

A rejection notch shall be provided for each zero doppler spectral component within the passband and also for each zero doppler spectral component that occurs in the transition region between the pass and attenuation bands until the attenuation is in excess of 70 db.

The requirements of each rejection notch are summarized as follows:

(a) One quartz crystal notch rejection filter shall be centered on 100 kc and additional notches centered at each multiple of the prf above and below 100 kc to the frequency where the overall passband filter is down 70 db.

(b) Each notch shall provide attenuation of at least 70 db within ± 1 cps of the specified center frequency. The notch width shall be less than ± 6 cps for attenuation greater than 3 db. This has been possible to obtain by cascading 5 stagger-tuned stages of bridge type filters using high Q quartz crystals as shown as shown in NRL Report 5587.

(c) The center frequency of each rejection notch shall be set and held to within ± 0.2 cps of the specified frequency. This will probably require temperature control of the quartz crystal filter elements. To eliminate warm-up time delay the temperature control may operate continuously, even when the filter is not in use.

GENERAL REQUIREMENTS

(a) Mechanical

(1) The composite comb filter for each prf shall be rack mounted in an enclosure which will match those of the remainder of the system.

(2) Each passband filter section shall be on a separate rack-mounted chassis with input and output BNC terminals available on the front panel.

(3) All crystals of the same offset frequency (of the 5 stagger-tuned stages) shall be located on the same rack-mounted chassis if possible. If more space is required extra chassis may be used, but crystal notches of different offset frequencies shall not be mixed on one chassis. An input and an output BNC fitting shall be provided on the front panel of each chassis.

Note: If the prf is divided without widening the pulse width, an appropriate bandpass filter (the same width as for the undivided prf) will be required and the number of rejection notches will be increased by the division ratio. If the division is by 2 it is likely that 2 chassis will be required for the crystal notches. The one half closest to 100 kc should be grouped on one chassis. The remainder should be combined on a second chassis. For division by 3, the one third of the crystals nearest 100 kc shall be on one chassis, the lowest frequency third on another and the highest frequency third on a third chassis.

(b) Electrical

(1) Each section of crystal filters shall have an amplifier to make up for any loss within the chassis and be capable of setting gain to unity with at least a 6-db reserve.

(2) Input impedance to each crystal chassis shall be a minimum of 20,000 ohms. Output impedance shall be less than 150 ohms.

(3) The output section of the bandpass filter shall contain an amplifier and a low output impedance driver which may be combined if desired. The amplifier gain must be adequate to compensate for any loss contributed by the input and output bandpass filter sections and by the output driver. The output load may be an unterminated coax cable of as much as 1500 mmf capacity or may be terminated in a 93-ohm characteristic impedance.

(4) The input-output amplitude characteristic of the overall composite comb filter with a 93-ohm output termination shall be linear to the extent that the output remains within 1% of the input voltage for inputs as high as 20 volts peak to peak when the overall gain is set for unity at 10 volts peak to peak input. This should be measured at a frequency midway between rejection notches.

(c) NRL Comb Filters

An existing 100 kc quartz crystal comb rejection filter designed at NRL has been in operation for over two years. It has provided rejection notches satisfactory in shape and stability for pulse repetition frequencies of 180, 90, 60, and 45 cps. The comb filter for 180 cps consists of five chassis, each containing 63 quartz crystals which provide a rejection notch at the carrier frequency plus 31 sideband frequencies above and also below the carrier frequency. The five chassis differ only in the offset tuning; all crystals of one chassis are tuned exactly to their specified sideband frequencies while in the other four chassis the offset tuning is -1.0 cps, -0.5 cps, +0.5 cps, and +1.0 cps. When the five chassis are operated in cascade a stagger-tuned rejection notch characteristic is obtained at each of the 63 frequencies. A double tuned transformer is provided at the input and at the output of each chassis. Each transformer was designed to be down less than 3/8 db from peak response over the bandwidth of ± 2.5 kc from the carrier frequency so that when eight were used in series the combined response would be down less than 3 db over this range. Additionally, the attenuation produced by the combination of eight transformers was to provide attenuation of at least 70 db for frequencies beyond ± 5.5 kc from the 100 kc carrier.

The comb filters for the other pulse repetition frequencies are identical except for the rejection notch frequencies. The 90-cps comb filter provided 63 additional notches so that when used in conjunction with the 180-cps unit a notch exists at each spectral component over the same bandwidth as before for a total of 126 separate rejection notches. Similarly, the 60-cps units operate in conjunction with the 180-cps unit and the 45-cps unit operates in conjunction with both the 180-cps unit and the 90-cps unit.

Quartz crystals are MT cut and each is mounted in an evacuated glass envelope. Many of their parameters were specified in their procurement. A few of these are: series resonant frequency, frequency tolerance, motional inductance, series resistance, the temperature of zero temperature coefficient, and shunt capacity. The zero offset stages operate 25 cps above the crystal series resonance as measured in TS-537/TSM. Since five were ordered for each notch frequency those for other offsets will operate between 24 and 26 cps above the crystal series resonant frequency. Frequency tolerance was +0.001 to -0.003%. Crystal "Q" values are generally in excess of 125,000.

When all crystals are obtained with the same turning point temperature (zero temperature coefficient) a simple temperature control of the entire enclosure (enclosed rack) is adequate for the specified frequency stability. The existing comb filters use a pair of cone heaters plus a blower for air circulation within a rack to produce uniform heat for temperature control. One thermostat controls the heater off-on cycle at the desired temperature. A second thermostat set about 10° higher is used as a safety to cut off heater power and operate a warning light whenever over-temperature is reached. All crystals on a given chassis are located within an enclosed compartment. This in combination with the evacuated crystal envelope cause a significant temperature lag which smoothes the temperature fluctuations external to the crystal enclosure.

APPROACH-RECEDE DOPPLER SEPARATION FILTERS

In coherent pulse doppler radars it is common to translate signals to a nominal zero intermediate frequency. With such a system, unambiguous doppler can be indicated for frequencies up to one-half the pulse repetition rate; however approach or recede information is lost. If an i-f placed at one-quarter of the pulse repetition rate is used, approach or recede targets can be identified by displacement above or below the i-f frequency, but the available unambiguous doppler extract is one-quarter of the pulse repetition rate.

It is desirable to both maintain all possible available doppler and to separate or otherwise identify approach and recede targets. NRL has developed one solution to the problem which is described in NRL Report 6079. In brief this method is to place a pair of complementary filters, each having a bandpass of one-half the pulse repetition rate, on the sides of the carrier with the crossover point upon the carrier (this carrier to be at some convenient i-f, such as 100 kc). Although approach and recede doppler can thereby be separated, all range resolution is lost. To preserve range information, the sideband filters can be gated "on" for a short part of the interpulse period. A workable system that retains the radar range resolution would have a filter pair for each range resolution element with inputs gated "on" at the appropriate range (time) delay and for a duration of one pulse width. At the output of the filters, range-gated, doppler-separated signals are available for further processing. This information is in the correct form for both doppler-time and doppler-range processing. That is, both forms of processing require short sample range gating prior to signal storage. An additional item of note is that if proper skirt design is secured the complementary filters can accomplish part or all of the required earth backscatter rejection.

THE SIGNAL PROCESSOR

Although the backscatter rejection comb filters and the doppler approach-recede filters are treated as separate items in this document, their function is considered as a part of the signal processor and may logically be an integral part of a digital system. Thus the signal processor, referring to Fig. 8, starts at the comb filter and ends at the displays. A brief on signal processing is that the desired very small signals are to be detected in the presence of very large signals and that the technique employed is that of narrow band spectrum analysis.

It may be helpful to give some illustrative signal tracing. With a transmitter and antenna as is designated herein (antenna gain > 20 db, peak power 10 megawatt, pulse lengths 250-1000 μs) and assuming an antenna terminal impedance of 50 ohms, the earth backscatter signals can result in antenna terminal voltages as high as 50 millivolts peak to peak near the front edge of the backscatter and being as high as one millivolt peak to peak at all useful radar ranges. Typical aircraft echoes to be detected and displayed amount to signals measured in the microvolt and hopefully fraction of a microvolt peak to peak levels at the antenna terminals. It is clear that some rejection of earth backscatter signals is desirable as early in the processor as possible. NRL has had considerable experience with a processor that takes short range gated samples of bi-polar video, stores upon a magnetic drum or disc with time compression and performs spectrum analyses upon the playback with a scanning filter. Since bandwidth narrowing down to one-tenth cycle is desired, the technique described is very attractive. The principal difficulty in NRL experience has been that the storage device possessed a limited dynamic range of about 30 db. This dynamic range is a serious limitation in dealing with meteor trail echoes, aurora-like echoes, near range targets and co-channel interference. It is felt that the storage device should possess a dynamic range of at least 60 db after backscatter rejection, and studies have indicated this dynamic range is possible with a 10-bit digital storage system.

(a) Requirements - the requirements can be stated as follows:

(1) Provide backscatter rejection with rejection notches fitted as closely to existing backscatter frequency distribution as possible. Working with 80-100 db signal to clutter ratios is the aim.

(2) Approach and recede separation into a range gated multiplicity of channels equal to twice the number of range elements.

(3) Short sampling from range elements and storage with time compression of the order of 40,000 to 1. Dynamic range to be 60 db, linear to ± 1 db. Storage time variable from 1 to 10 seconds for doppler versus range analysis and from 60 seconds to 5 minutes for doppler versus time analysis.

(4) Scanning filters with equivalent resolution bandwidths from one-tenth to one cycle per second should be provided to perform the spectrum analysis in a time of a few seconds. Consideration should be given to frequency sidelobe suppression.

(5) One mode of radar operation is to dwell upon selected frequencies for only short periods of time. Some means of suppressing the backscatter leakage associated with these frequency moves is necessary. Dwell times as short as 3 seconds are a requirement and down to 1 second desirable.

(6) The outputs from the processor are to be in the form of doppler-amplitude versus range element and doppler-amplitude versus time for each range element.

$\dot{R}$-R, $\dot{R}$-T GATED AND AZIMUTH ANGLE DISPLAYS

The system display shall include one set of cathode ray indicators for visual readout and one set of cathode ray indicators and cameras for photographing the information on 35 mm film. While the basic system displays are to be designed for manual readout and recording of the information more complex automatic readout and recording are considered necessary thinking on the portion of the installation to increase data rate. The displays shall show the date, time, frequency of operation, range segment and azimuth.

SPEED-RANGE INDICATORS

One set of indicators, designated the SR display, shall show radial speed vs range for each major range interval; 500-1000 n. mi., 1000-1500 n. mi., 1500-2000 n. mi. with range horizontal and speed vertical. Approaching targets shall be displayed separately from receding targets. Consideration should be given to the possibility of showing approaching targets on one half and receding targets on the other half of a cathode ray tube indicator. These SR displays shall have range and speed strobes to assist the operator in measuring range and speed of targets. The range strobe shall be capable of being read to 1/10 pulse width expressed in nautical miles. The speed strobe shall be capable of being read to 1/2 the speed resolution of the system. The speed calibration shall be automatically adjusted for the operating frequency.

The target shall brighten the display and the display shall have either a hard limiting characteristic or a logarithmic response so as to avoid spot defocusing and screen damage. The display shall have suitable screen storage to retain the information from one three second scan period to the next. A means shall be provided to store the information so that a scan to scan comparison can be made when the antenna is scanned at one beam width every three seconds to one beam width per minute. This storage and associated display shall be priced separately.

SPEED-TIME INDICATORS

There shall also be provided a set of displays with speed vertically and time horizontally called the ST display. The operator shall be able to activate up to 20 ST displays of selected ranges intervals, the range intervals being equal in extent to the transmitted pulse width expressed in miles. He shall be able to set these range intervals adjacent to each other or at any of 20 selected ranges. These displays shall be furnished with a speed strobe capable of being read to 1/2 the theoretical resolution of the equipment. The time calibration shall be displayed so that an operator can determine time to an accuracy of one second.

RANGE-AMPLITUDE INDICATORS

In addition, there shall be a range vs amplitude display of the video signal being processed for each SR display. The range displayed on the SR display shall be suitably identified and the range interval being displayed on the various ST displays shall be suitably identified.

There shall be such additional displays as the designers deem necessary for the proper operation and maintenance of the equipment; for example: the i-f output of the receiver at each i-f frequency, the input to the comb filter and the output from the comb filter, and the output from the approach and recede filters. Some of these may be switched in, but where an oscilloscope is required for routine maintenance, it is well to consider a permanent installation.

There should also be supplied a tape storage system capable of storing the video, before processing and with sufficient stability to operate with the data processor, so that stored data can be restudied for an examination of critical events.

The azimuth angle display and the frequency-range display means should be located and associated with the basic displays.

THE ACCELERATION GATES

Introduction. - The objective of acceleration gates is to extract, in real time, the maximum possible quantity of information from the radar echo by providing acceleration as an additional parameter while retaining the velocity and range parameters, by maximizing the resolution of all three parameters, and by maximizing the signal amplitudes of accelerating targets. Improved detection, separation, and identification of all types of targets accrue from the increased kinds and rate of flow of information.

Accelerating targets such as missiles spread their echo energy over many velocity bins of a velocity analyzing and integrating radar, with consequent loss of system sensitivity and velocity resolution. An attempt to meet this problem by increasing the bandwidth of the analysis narrow band filtering will result in a lowered velocity resolution and system sensitivity.

The philosophy of the acceleration gate design was to meet this problem, at the same time acquiring the acceleration parameter, not by widening the velocity filtering but by employing sophisticated spectrum compression techniques to collect the spread spectrum energy of the accelerating target into the same narrow frequency band or single frequency response of a non-accelerating target. This method not only permits the greatest possible acceleration, velocity, and range resolution, but also provides a signal of enhanced amplitude. Acceleration as an additional dimension of information is realized in the spectral compression operation where the target acceleration is determined by a profile matching process as shown in NRL Report 5570.

Acceleration along with velocity and range is measured by means of a set of parallel channels called the acceleration gate system. All three parameters are quantified in real time with an analysis time no greater than was formerly required for only velocity and range. A span of acceleration is covered by designing each channel to match or respond to a given acceleration increment or bin. All velocity and range bins are sequentially interrogated for a target of matching acceleration by this channel (acceleration gate). Simultaneously, other acceleration bins are established by the additional parallel channels each responsive to a given increment of acceleration. These channels also interrogate all velocity and range gates for targets of their respective acceleration bin.

<u>Gate System Coverage</u> - A block diagram of the subject acceleration gate system is shown on Fig. 11. A more detailed description of the system will be given elsewhere.

The acceleration gate system is capable of providing target acceleration, velocity and range data. Table I shows the coverage, accuracy, and resolution realizable for each parameter at radar operating frequencies of 7.0 and 30.0 Mc and a 2½ second storage time.

Range coverage as shown on Table I is divided into 500 n. mi. blocks for display purposes, the particular block presented being selected by the operator.

Unambiguous velocity coverage is provided without gaps between the values shown. Ambiguous coverage extends to higher values.

Acceleration coverage is continuous from 0 to 17.5 G at either operating frequency. At the higher operating frequency additional resolution and accuracy may be realized at the expense of reduced coverage by changing to a lower ratio (BW_R) between analysis predetection bandwidth and twice the post detection video bandwidth. As indicated on the table, fifty acceleration gates or channels (each responsive to a constant acceleration increment) are needed for a 17.5 G coverage. When coverage is extended to both positive and negative accelerations the system will require a total of 100 acceleration channels for operation with a storage time of 2½ seconds.

The acceleration gate system processes data in real time. Therefore, the system characteristics of Table I are real time characteristics limited only by the data storage time which in this case is 2½ seconds.

[redacted]

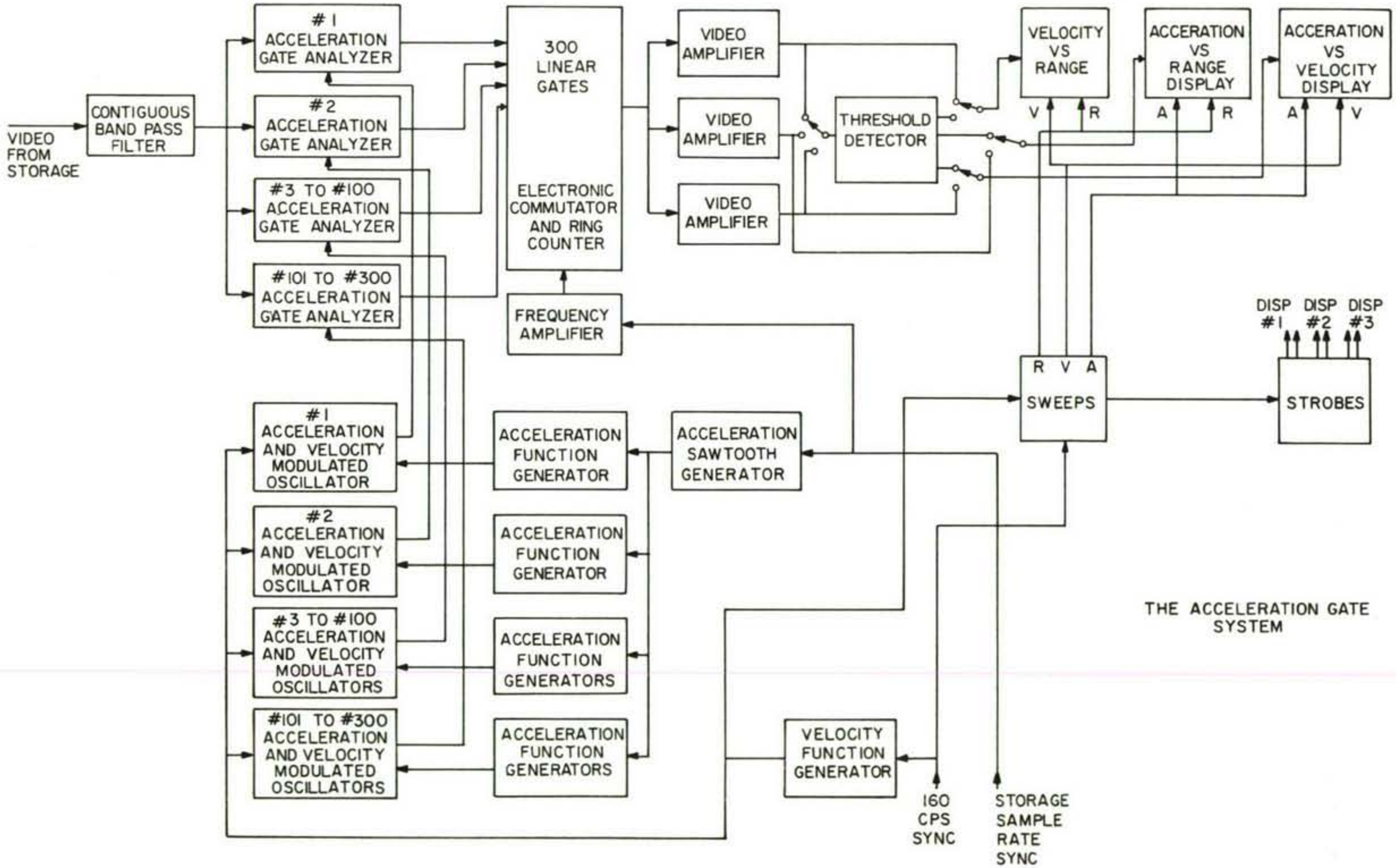


Fig. 11 - The Acceleration Gate System

[redacted]

[redacted]

Table I
for 2½ Second Storage Time

	Operating Frequency		
	30 Mc		7.0 Mc
	$BW_R = 1$	$BW_R = 5$	$BW^R = 1$
Range			
Coverage	500-2000 nm	500-2000 nm	500-2000 nm
Unambiguous Velocity			
Coverage			
161 PRF	60-785 Kts	60-785 Kts	250-3350 Kts
80 PRF	60-392 Kts	60-392 Kts	250-1675 Kts
40 PRF	60-196 Kts	60-196 Kts	250-837 Kts
Resolution and Accuracy	3.8 Kts	19.0 Kts	16.2 Kts
No. of Velocity Bins(161 PRF)	185	38	185
Acceleration			
Coverage	0 to 40 G	0 to 20 G	0 to 17.5 G
Resolution and Accuracy	0.08 G	0.4 G	0.35 G
No. of Acceleration Bins	50	50	50

Table II shows the acceleration gate system coverage for a storage time of 10 seconds.

Velocity and range coverage remain the same as shown on Table I. Velocity resolution and accuracy have been kept comparable through a different selection of pre to post detection bandwidth ratios (BW_R). However, it should be noted that higher resolutions and accuracies are possible if BW_R's less than 4 are employed. Acceleration resolution and accuracy are greater than those shown on Table I because the velocity resolution is established over a longer sampling and storage period.

The number of acceleration gates is basically determined by the highest operating frequency, the storage time, and the desired acceleration coverage and resolution. It is also influenced by several other considerations. With storage times as short as 2½ seconds all missile targets read out of storage will be considered to possess a constant acceleration. This assumption is not valid with longer storage times where some mismatching can occur if constant rather than non-constant acceleration modulation profiles are employed in the matching process.

The deviation of missile acceleration from a constant value amounts to only about 0.2 G in the most extreme situations and over only a few seconds portion of the powered flight time when measured over 10 second intervals of time. Reference to Table II shows that mismatching occurs at the higher operating frequencies with 10 second storage. Table II

[redacted]

Table II
for 10 Second Storage Time

	Operating Frequency			
	30 Mc		7.0 Mc	
	$BW_R = 4$	$BW_R = 8$	$BW_R = 4$	$BW_R = 8$
Range				
Coverage	500-2000 nm	500-2000 nm	500-2000 nm	500-2000 nm
Unambiguous Velocity				
Coverage				
161 PRF	60-785 Kts	60-785 Kts	250-3350 Kts	250-3350 Kts
80 PRF	60-392 Kts	60-392 Kts	250-1675 Kts	250-1675 Kts
40 PRF	60-196 Kts	60-196 Kts	250-837 Kts	250-837 Kts
Resolution & Accuracy	3.8 Kts	7.7 Kts	16.2 Kts	32.4 Kts
No. of Velocity Bins (161 PRF)	185	92	185	92
Acceleration				
Coverage	0-1.0 G	0-2.0 G	0-4.4 G	0-9 G
Resolution & Accuracy	0.02 G	0.04 G	0.088 G	0.18 G
No. Acceleration Bins	50	50	50	50

also shows that acceleration resolution accuracy and coverage which is obtainable with selected bandwidth ratios and 50 acceleration gates responsive to constant acceleration. The coverage may be extended by adding acceleration gates or by increasing the BW_R. An increase in BW_R will also reduce the mismatch. Alternatively, the mismatch may be reduced by setting up additional acceleration gates responsive to non-constant acceleration. Ideally this results in a better output signal-to-noise ratio. If these additional gates are to be added, two would be added for each constant-acceleration acceleration gate. Since 50 positive and 50 negative constant acceleration gates are required for either a $2\frac{1}{2}$ or 10 second storage time, a total of 300 acceleration gates would be required. It is recommended that the method of reducing mismatch include the additional acceleration gates as well as the provision for an increase of bandwidth ratio.

Examination of Tables I and II shows that the spectrum compression or profile matching processes of the acceleration gate system has in each case permitted optional operation with the narrowest possible (optimum) post detection analysis bandwidth, which operation yields the highest possible resolution of acceleration, velocity, and range for all targets (aircraft or missile, with or without high acceleration) consistent with maximization of target signal amplitudes.

Target discrimination capability is enhanced by both addition of acceleration data and the improvement in resolution of range and velocity data.

Recede-Approach Indication - One mode of acceleration gate operation would utilize the output of the sum channel data storage as the input to the acceleration gate system. In this mode velocity sense would be indeterminate but all targets would be processed. Sense of a target may be resolved by switching briefly from an unfiltered sum storage input to a sum storage input that has been filtered for approach only or recede only signals. If a switch is made to an approach channel from an unfiltered sum channel and no signal is found then the sum channel signal can be assumed to be a receding target. An alternate solution is to parallel the acceleration gate equipment to allow continuous determination of approach and recede sense.

Data Processing - Addition of the acceleration parameter causes a considerably higher rate of data flow in this system. Outputs from all of the parallel acceleration gates occur simultaneously. Since the displays can only accept sequential signals, the parallel output must be converted to sequential form by time sharing commutation.

After commutation the three parameters may be displayed on three cathode ray tubes having formats of acceleration vs velocity, velocity vs range and acceleration vs range. In any of the three displays one of the axes will contain many more data elements than the other, so many in fact that they may not be resolved. This means that if the display is operated with a light painting of noise the noise will build up on the overlapping lines (with a long persistence phosphor) reducing the overall signal-to-noise ratio. Since the other axis contains many fewer lines this problem can be resolved by equalizing the horizontal and vertical line requirements through the use of auxiliary sweeps. An alternate solution is to rule out attempts to visualize targets through noise on the displays. Line overlap will then be of no consequence and only basic simple sweeps will be required at the displays.

Dynamic Range - Cathode ray tubes have limited dynamic ranges which require consideration. The matching process performed in the analysis discriminates between targets of various accelerations. Targets which do not match have their energy spread and reduced in amplitude. However, very large non-matching targets (or interferences), even though their energy is spread and reduced, in some cases are still capable of limiting the discrimination capability. Therefore, control of dynamic range is also desirable here.

It is accomplished by placing ten contiguous equally wide bandpass filters covering the input video band at the common input of the parallel acceleration gates. The block diagram is shown on Fig. 12. Each filter is followed by a limiter. The white noise level at the output of each filter will be equal. The limiting level of each limiter is set just equal to the peak to peak noise level that is exceeded only 0.01% of the time. The signals, after output filtering that is identical to prelimiting filtering, are then linearly recombined into a single path to feed the parallel acceleration gates. With the limiters set above noise level they will not influence the integration process and the extraction of small signals out of noise.

The purpose of the contiguous filters is twofold. One is to narrow the span between the minimum detectable signal level and the limiting level, hence controlling the dynamic range as desired. The second is to minimize the effects of interference or jamming in one doppler decile from spreading to the others. With the dynamic range properly controlled even very large amplitude interference or signals which might otherwise spread over a large velocity range will not appear at the display beyond a few resolution bins.

The contiguous bandpass filters will be described in more detail later.

<u>Dual Parameter Time-Track Displays</u> - Targets may persist for only seconds or for some time. In either case a direct view storage display with controlled retention time (in minutes) would aid the operator. In the first instance it would aid him to discover the target and in the second case interesting target tracks will be generated which could be studied at the operator's leisure. Therefore it is desirable to parallel each of the three previously mentioned displays with direct view storage displays which have a controllable retention time of several minutes. It is of interest to note the possibilities of these three displays. Acceleration-velocity time tracks will be available on one, acceleration-range time tracks on the second, and velocity-range time tracks in the third.

<u>Data Records</u> - There is a requirement for a permanent 35 mm film record of selected data. This need can be satisfied by paralleling the displays with oscilloscopes equipped with automatic 35 mm cameras synchronized with the velocity sweep with a manual option. Three oscilloscopes would be of the non storage type and three of the storage type with controllable retention time.

All displays shall be equipped with lighted date, time, and azimuth indicators which may be photographed along with the display.

Acceleration, velocity, and range information for each target can be obtained by a suitable decision threshold means; and, together with date, time, azimuth and other pertinent data should be stored in a memory subject to immediate recall for local or remote use and further processing or computation if desired.

[redacted]

Specified Acceleration Gate System - The acceleration gate system discussed previously is shown in block diagram form on Fig. 11. It consists of a contiguous bandpass filter, 100 constant acceleration gate channels, 200 non constant acceleration gate channels, 300 linear video gates to sequentially sample all channel outputs, a choice of direct video or threshold detector output as desired and three displays. Velocity vs range information is presented on the left hand display, acceleration vs range on the middle one, and acceleration vs velocity on the right hand one. The storage displays and the camera displays are not shown on this figure because they are merely operated in parallel with the three displays shown. Sweep, blanking, and strobe circuits for operation of the displays complete the system.

An acceleration gate channel consists of an analyzer, an acceleration and velocity modulated oscillator, and an acceleration function generator when required. Common acceleration and velocity modulation functions are obtained from an acceleration sawtooth sweep generator and a velocity function generator as shown on Fig. 11.

Test equipment, including a signal simulator which will be described later, is also required as an aid to setting and maintaining the system in optimum operating condition.

Additional details not covered here may be found in the NRL Reports 5876, 5899, 5900 and 5926. They describe the existing acceleration gate system which although not identical with the subject system does have many points in common.

Contiguous Bandpass Filter Set - A contiguous bandpass filter set is illustrated on the block diagram of Fig. 12. Two sets are required, one to cover the 160 to 3000 kc frequency range and the second to cover 40 to 745 kc. Each set will contain ten bandpass filters overlapping at their 3 db points to cover the respective frequency ranges. Frequencies below 40 and 160 kc are blocked to attenuate harmonics of the storage sampling repetition rate. Each of the ten bandpass filters should have a 3 to 60 db shape factor that is less than 5 to 1 and the attenuation in the stopbands should exceed 50 db.

Since the video noise input from storage will run about 0.25 volts peak to peak an amplifier is shown in each filter circuit of the block diagram to raise this level to a value that will permit efficient limiting. The transition from no limiting to full limiting should take place over only a 3 db change of signal level. A gain control should be placed in each of the ten amplifiers (with accessible test points) to permit equalization of all output levels. Each amplifier should be linear within 2% from the above limiting-level down 40 db.

A bandpass filter follows each limiter. In each case the filter is identical with the one that preceded it ahead of the video amplifier.

[redacted]

[redacted]

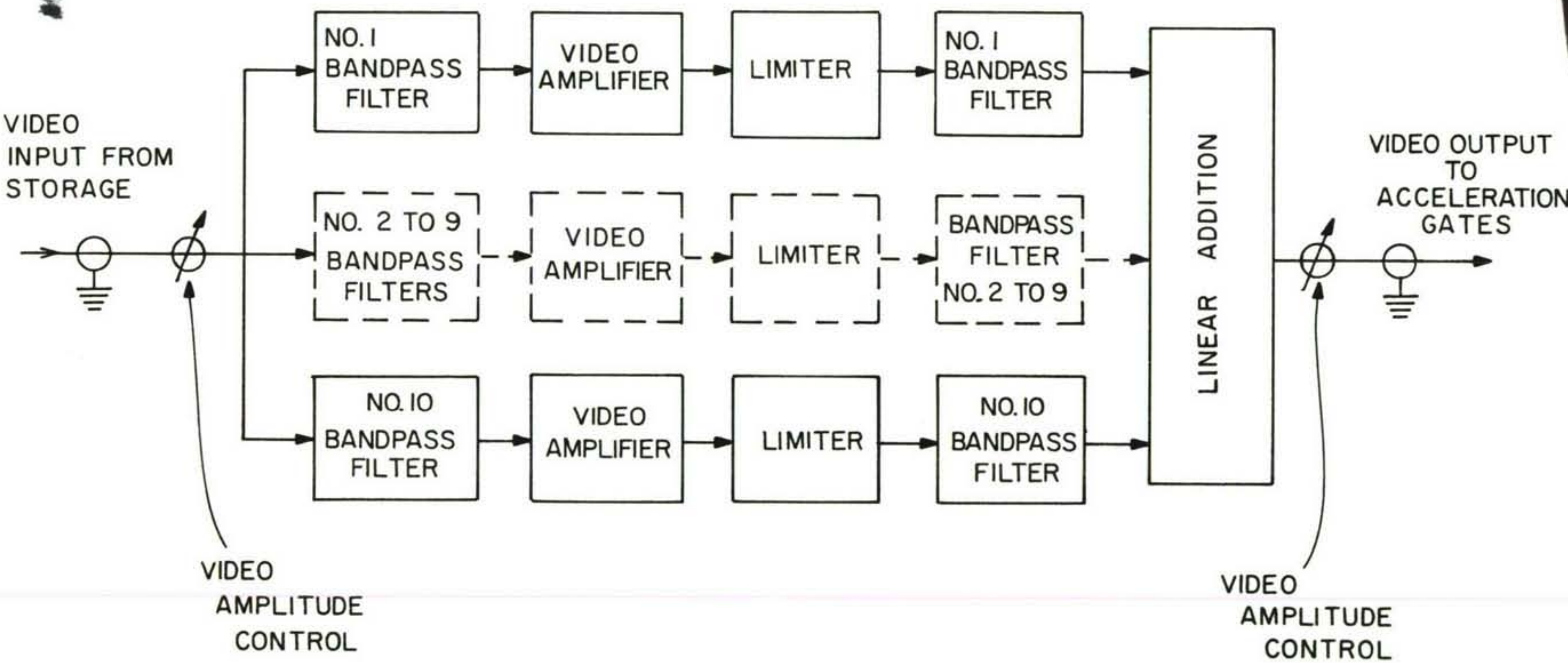


Fig. 12 - Contiguous Filter Set

[redacted]

The purpose of the second identical filter in each of the ten filter circuits is to eliminate harmonics introduced by limiting of very large interference or very large signals. Outputs of the ten filter circuits are next combined linearly into a single output which drives the parallel acceleration gates.

In Fig. 12 a gain control is shown at the main input to allow the ten limiting levels to be set simultaneously after equalization of all individual levels. A gain control is shown at the output to allow the input to the parallel acceleration gates to be set to a standard level.

The overall filter set should be linear within 2% from the limiting level down 40 db.

<u>Analyzer</u> - The analyzer may be considered to be a superheterodyne receiver with a scanning oscillator and predetection narrowbanding in the i-f amplifier and further narrowbanding after detection as illustrated on Fig. 13. The input video from the storage memory is searched for target signals by systematically step scanning the oscillator frequency. All range bins of a range block are searched for signals of a given velocity before the scan is stepped to the next velocity bin.

The velocity bin width is determined by the bandwidth of the predetection filter. To minimize detection loss the scan frequency step should not greatly exceed half the velocity bin width in frequency. Bandwidth of the post detection filter is chosen for optimum radar performance.

As long as a target maintains a constant velocity its doppler signal frequency as stored in the memory will also remain constant. Upon readout of the memory the signal is placed in the proper velocity bin by the step scan. Since the signal frequency remained constant during the time the storage was being filled it will, upon readout, remain within a velocity bin width as determined by the predetection filter bandwidth and produce a full amplitude response.

However, in the case of the accelerating target the doppler signal frequency may change considerably in the period of the stored sample. This means that the stored doppler frequency can extend over a large number of velocity bins reducing the amplitude response of any single velocity bin. In other words the spectrum of the target has been spread out by acceleration. Spectrum spread is a function of acceleration. This suggests that a measure of the spread defines acceleration. Furthermore, it also suggests that compression of the spectrum into a single or narrow frequency band, when analyzed, will produce a narrow signal spike with enhanced amplitude and improved resolution.

[redacted]

Spectral compression is accomplished in the analyzer by acceleration frequency modulating the scanning oscillator with a function having a period equal to the storage sample period and with a slope and shape which matches the doppler frequency profile of the accelerating target signal. With perfect matching a constant i-f frequency results which will remain within a velocity bin bandwidth to produce a maximum signal amplitude response.

The acceleration modulation is repeated once for each range bin until all range bins have been searched at all velocities before recycling. Other acceleration bins are formed by paralleling analyzer channels thus forming multiple acceleration gates.

A block diagram of the analyzer is shown on Fig. 13. The video amplifier provides isolation and some gain. The modulated oscillator input is mixed with the video input from the storage memory by a balanced mixer. A predetection bandpass filter selects the sum frequency. This signal is amplified at the i-f frequency and then is detected. A low pass filter serves as the post detection filter.

The overall linear dynamic range of the analyzer shall be 60 db with 1.0 volt peak to peak as the maximum input level to be handled. Within this range non-linearity shall not exceed 2.0%. Overall gain shall be such as to raise an input video pulse level of 0.25 volts peak to peak to 4.0 volts peak at the output. Provision shall be made to adjust the output level over a range of -6 db to +12 db. To minimize detection loss at the display the analyzer input-output frequency response shall be flat within 1.0 db over the input video frequency band.

It is necessary that the acceleration gate system perform in an optimum manner for various changes in pulse repetition period, pulse width, and radar operating frequency. The effect on the analyzer is that of requiring a change in bandwidths and/or a change in the ratio of bandwidths of the pre and post detection filters. Ideally the change in mode of operation should be controlled at a centrally located place which would of necessity be remote from the analyzers. Therefore, the necessary changes in pre and post detection filter bandwidths must be effected with remotely controllable switches which must be capable of switching in any of a number of filters in each position.

<u>Range Rate And Acceleration Modulated Oscillator</u> - One oscillator, capable of simultaneous frequency modulation by both a range-rate input function and an acceleration input function, is required for each acceleration gate channel. The range rate modulation waveshape will be a staircase of steps whose duration will be $\frac{1}{161}$ second, and there will be one step for each range rate sample. The acceleration modulation waveshape for the case of constant acceleration will be a linear sawtooth with a total width equal to the storage sample interval. Other irregular waveshapes of the same prf may also be used and represent other non-constant acceleration functions.

[redacted]

[redacted]

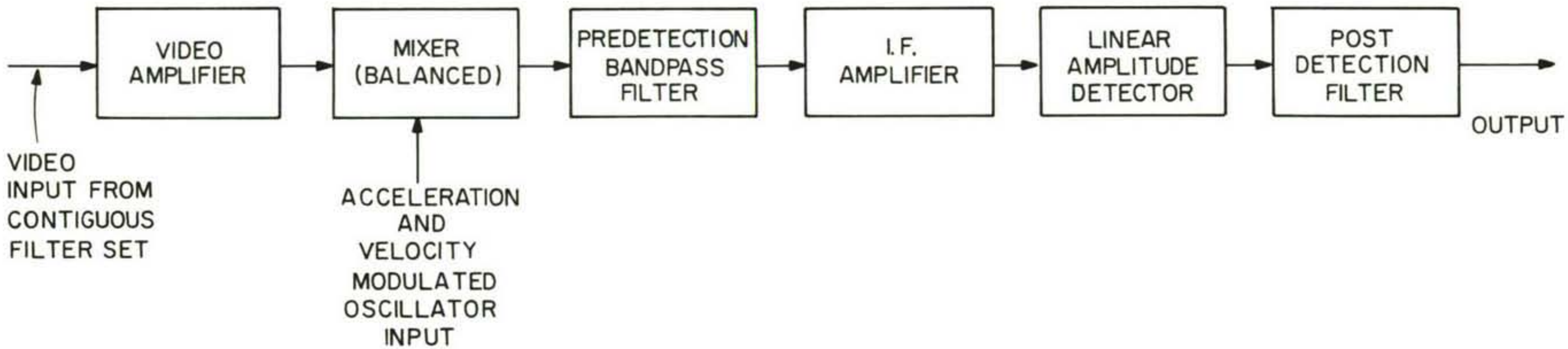


Fig. 13 - Analyzer

[redacted]

In general, the range rate modulation will occur at a very slow rate and the acceleration modulation at a much higher rate according to the mode of operation.

The oscillator shall operate over a frequency range equal to the product of the storage compression ratio by the maximum non-ambiguous doppler frequency for the full prf of 161 cps. It shall be possible to sweep the full frequency range by modulation input voltages applied to either the range rate input or the acceleration input. The frequency vs voltage characteristic for either modulation voltage input shall be within ± 1.5% of a linear characteristic at any point. A given amplitude acceleration signal shall cause the same oscillator frequency change for all values of range rate input volts which are required to produce the full oscillator sweep range in the absence of an acceleration a-c voltage input. It is anticipated that compensating circuits will be required to meet the acceleration modulation linearity requirements.

When the prf is divided by two (to 80 cps) the required range rate sweep is also divided by two, but the required acceleration sweep range remains unchanged. Similarly, a prf of 40 cps requires only one-fourth of the original range rate sweep range yet requires the full acceleration sweep range. Reduction of range rate sweep range is accomplished by reducing the range rate peak to peak input step voltage. Care must be exercized to insure that the starting frequency is correct when sweep range is changed.

Oscillator frequency stability shall be adequate to maintain the starting frequency of any sweep within ± 2 kc of the specified value for all operating conditions after initial warmup stabilization. It should be noted that a slight variation in starting frequency is required for different modes of operation.

The output amplitude over the full frequency range shall remain constant within ± 1.0 db when driving its intended load.

<u>Acceleration Modulation Function</u> - The acceleration input function to the modulated oscillator is provided by the acceleration sawtooth generator in combination with a function generator. The sawtooth must be highly linear, within ± 1% of a straight line function for at least 85% of its period; hence, the flyback portion will not exceed 15% of the total period. The actual period (storage sample period) is equal to the readout time of one range gate sample that has been stored over the full integration period and a synchronizing input pulse is required to establish this precise period.

Modulation functions for constant accelerations are linear sawtooth signals where a choice of the sawtooth amplitude determines the equivalent acceleration. In the case of the 100 constant-acceleration acceleration gates linear sawtooth functions will be entirely adequate to match the modulated oscillator frequency change to that of the signal return from an accelerating target. All that is required of the function generator is to set sawtooth amplitude (in this case it may be a simple potentiometer). One function generator is required for each acceleration channel but a single sawtooth generator may supply all function generators if suitable drivers are provided.

In the case of the 200 non-constant-acceleration acceleration gates the function generator must provide modulation functions that are non-linear to allow a more precise oscillator match to a return signal from a target whose change in radial velocity during the integration period cannot be considered linear, with time. Two non-linear function generators will be added for each linear function generator (making up three acceleration gate channels) and they will each be set for the same precise peak output voltage so they will produce the same overall oscillator frequency change during the readout integration period. The non-linear functions will deviate from the linear function at its midpoint by a voltage difference which will cause the oscillator frequency to change an amount equal to one and a half acceleration gate bin widths. One non-linear function will increase frequency (above that obtained with the linear function) at the midpoint while the other will decrease frequency at the midpoint. The shape of the non-linear curves may be either two straight line sections of different slopes or a smooth curve through the points as described above. Consideration should be given to means for quickly changing the circuits producing the non-linear functions.

The amplitude stability of the modulating waveforms must be adequate to maintain correct oscillator frequency to within one-half the predetection filter bandwidth.

A d-c reference must be controlled in the function generators (as well as in the modulated oscillator) so that for positive accelerations the starting frequency does not change when the sweep range is changed. For negative accelerations the end point is maintained at a constant frequency when the sweep range is altered.

Whenever a change in predetection bandwidth (change in resolution) or a change in storage time occurs the amplitude of the acceleration modulation of all acceleration gates will also have to be changed to bring the acceleration coverage to the desired values. This may be accomplished by remotely controlling the output amplitude of the acceleration sawtooth generator with a step attenuator. All acceleration gates receive this signal, hence, all are controlled simultaneously.

The repetition period of the acceleration sawtooth generator must equal the storage sampling period. This change must be accomplished remotely. Output sawtooth amplitude must remain constant with change in period; also the starting frequency of the oscillator sweep should remain fixed.

Electronic Sampler - Signals may appear simultaneously at the outputs of all 300 acceleration gates. The signal appearing at the output of any one acceleration gate arises from a search of all range bins of a range block for a given velocity bin. The same range block is searched for all other velocity bins. All of these are searched for one acceleration bin. Signals from other acceleration gates likewise arise from a search for all range and velocity bins for the corresponding acceleration bin.

For display purposes it is necessary to sort this information into meaningful sequences. The 300 gate electronic commutator shown on Fig. 11 is intended for this purpose. It must sequentially sample the output amplitudes of all 300 acceleration gates twice within the time of one range bin period. This time is established by the intersample period of the storage memory.

The 300 gates must have a signal dynamic range of 60 db with 10 volts peak as the upper limit. They must also be linear overall within 1.0% for the full dynamic range of amplitudes.

The 300 linear gates may be electronically commutated by a ring counter. Ring counter synchronization may be to the 600 harmonic of the storage memory sampling rate (add harmonic numbers for flyback time). If the sampling rate is changed the commutation rate must be changed a like amount.

A low output impedance driver is required.

Video Amplifier - Each display will be driven from a video amplifier whose input is the sampled acceleration gate output. The time of one sample may be as short a duration as 0.45 microseconds for the worst case of highest prf (160 cps) and 300 acceleration gates each sampled twice per range gate. The amplifier frequency response should be capable of passing a rise and fall time of 0.05 microseconds which will retain a sufficient flat top of the sampled pulse. A 7 Mc response when driving its normal load impedance should be adequate. The overall gain shall be 1000 which allows nearly 14 db excess over absolute minimum, and a gain control shall be included to permit setting gain anywhere between zero and maximum. The input-output voltage characteristic must be linear within $\pm$ 2.5 percent.

The input signal is unipolar, positive, and referred to ground. The sampled amplitude may vary greatly for any or all gates so that the average voltage level will be expected to vary greatly with received signal. Consideration should be given either to dc coupling or to dc restoration at each stage throughout the video amplifier.

The output stage must have the capability of driving the displays to the specified levels via a coax cable. The coax cable will require termination in its characteristic impedance unless its length is kept very short.

<u>Threshold Detector</u> - A threshold detector circuit shall be provided to generate an output pulse (that may be adjusted in width and amplitude) whenever the input video signal increases above a selected threshold level. In one mode of operation each of the three cathode ray tube displays is driven from its corresponding video amplifier. In other modes of operation any one, two, or all three displays may be driven from the threshold detector; thus a separate threshold detector output is required for each display. Each of these outputs will need an independent control of pulse width and amplitude. All three outputs shall have pulses initiated from a common trigger circuit and it shall be possible to select the video amplifier from which the trigger is derived.

Remote and local switching is required for selecting the input video that is applied to the trigger. It is also required for selecting the input video that is applied to the trigger. It is also required for selecting either the direct video or the threshold detector output as drive for each of the three displays. A remote control is needed for adjusting threshold level. Local controls will be necessary to adjust pulse width and output amplitude for each output circuit.

Threshold level shall be continuously adjustable from 5 volts to 70 volts and hysteresis shall be kept as small as possible consistent with stable operation. Each of the pulse outputs shall be adjustable in width; one output from 5.0 to 120 microseconds for the velocity range display, and the other two outputs from 0.25 to 10 microseconds. The amplitude of all three shall be adjustable from zero to 100 volts peak. The output impedance is to be less than 150 ohms.

<u>Acceleration Gate System Displays</u> - Three cathode ray tube displays will present the entire output data of the acceleration gate system in real time. One CRT will show range-rate (vertical) versus range outputs for all acceleration gates (including a zero acceleration gate). A second CRT will show acceleration vs range for all range-rate gates; and the third CRT will show acceleration vs range-rate information for all range gates. The acceleration axis will be calibrated for zero acceleration at mid scale. Accelerations above zero will be positive to indicate an increase in range rate with time, and below center will indicate a decrease in range-rate vs time. The constant-acceleration gates will be separated by equal increments of acceleration over the total acceleration covered. The total acceleration coverage will be obtained with 50 positive and 50 negative constant-acceleration gates. A pair of non-constant-acceleration gates (described elsewhere) are added for each constant acceleration gate, positioned one above and one below, at the displays. The CRT's may be identical for all three displays and should have at least a 10 inch diameter (or diagonal if a rectangular tube is used). The raster aspect ratio may be 4X3 with the longer dimension in the vertical direction for all three displays. A resolution of at least 500 lines is needed. The phosphor should have sufficient

initial brightness for photographing the displays and sufficient persistence to view over the full scan period. A dual phosphor might be highly desirable. The display tube supply voltages shall be regulated to maintain brilliance and focus over wide limits of signal inputs.

A graticule that is calibrated in both horizontal and vertical directions is required, and it should be illuminated, possibly from the edge, so that it may be properly exposed in photographs of the display. Since the scale calibration will be a function of the operating mode, means shall be provided to automatically indicate the scale in use when the operating mode is selected and switched into operation.

Control of intensity, focus, horizontal size and centering, vertical size and centering, and graticule intensity shall be available at each display. A strobe position and strobe intensity is required for each axis of each display.

A number of indicators must be suitably positioned and adequately illuminated to appear in the photographs of the displays and also appear visible to the operator. These indicators shall include: time in hours, minutes, and seconds in either digital or clock form; date in month, day, and year; antenna bearing in degrees; transmitter frequency which may be coded to a one or two digit indication; receiver gate setting (range block) which may be a single digit code; and horizontal and vertical strobe calibration.

Suitable camera mounts and cameras shall be provided on displays parallel to the main displays to photograph each type of displays. One type camera shall photograph once for every two range rate sweeps on 35 mm movie film. Means shall be included for operating the shutter or otherwise exposing the film in synchronism with the range rate sweep. The second type photograph is to be a still camera of 10 second developing time (Polaroid). In both types the subject material of raster plus other associated indicators shall essentially fill the field of the camera. The mounts shall be rigid so they are not inadvertently moved or misadjusted.

Three additional displays will be direct view storage types, where one will be operated in parallel with each of the main display CRT's. Storage capability shall be adjustable up to a maximum of ten minutes.

Display Sweeps - Three sweeps, range, range rate, and acceleration, are required for deflection of the three displays. Two are applied to each display. First, the range sweep is a sawtooth waveform with a period of $\frac{1}{161}$ second regardless of prf. It shall be synchronized from a 161 cps rate that is synchronous with the transmitter pulse, and it will be suitably delayed to make a signal of known range appear at the correct position on the range rate vs range and the acceleration vs range displays. A blanking signal will be generated equal in width to one range gate and applied to the intensity input of the display to provide blanking during retrace time.

The second or range rate sweep is a staircase waveform where each step is equal to $\frac{1}{161}$ second in width and the number of steps is equal to the number of range-rate samples. The step rate is maintained exactly synchronous with the range-rate input to the modulated oscillators that have been described elsewhere. This display sweep may be driven from the same sweep generator. A blanking pulse must be generated to cut off the CRT beam during retrace. In each display a blanking pulse is generated for retrace of each of the sweeps. These are added together before applying to the CRT intensity input.

The third sweep, acceleration, occurs at the fastest rate of the three sweeps. It is a sawtooth waveform with a period equal to that of the electronic sampler. It must be synchronous with the acceleration sampling commutation. A blanking pulse is generated equal in width to retrace time and applied as in the other displays. This blanking pulse width may be only one or two microseconds for some operating conditions. The retrace time which also determines blanking pulse width is made as wide as possible to avoid high amplitude pulses in the deflection coils when magnetic deflection is employed.

All sweeps will have amplifiers and driver stages capable of providing a full raster width sweep on the displays for all modes of operation.

Strobes - A strobe shall be provided for each axis of all three displays. It shall present a narrow intensified line on the display that may be manually positioned by the operator. A control of strobe intensity shall permit adjustment from complete cutoff to a full brightness easily seen or photographed with the display. The strobe readout shall be presented by lighted indicators which shall be accurate to within 1% for the range strobe, within one range rate gate for the range rate strobe, and within one acceleration gate for the acceleration strobe. The indicated readout shall automatically change to correct scales when the operating mode is changed.

Mode of Operation - The acceleration gate system is very flexible; therefore, it is important that all functions be optimized for a desired mode of operation. Provision shall be made for the remote control of these functions, which have been described, at a centrally located control console near the displays.

The type of target will determine the acceleration coverage and signal storage time required. Its range will determine the radar operating frequency, pulse recurrence frequency, and pulse length.

Reference to Table I shows the acceleration coverage obtained for a $2\frac{1}{2}$ second signal storage time. It will be noted that in order to maintain a large acceleration coverage it was necessary to change the ratio of pre to post detection filter bandwidths from one-to-one to 5-to-one for a comparable change in radar operating frequency. Actually only the predetection bandwidth changed since the post detection or video filter bandwidth, which is optimized for radar pulse length (that for a prf of 161 cps in this case) was assumed constant. The above ratio is actually the ratio between predetection filter bandwidth and twice the low pass filter bandwidth after detection.

Full coverage of acceleration over the radar frequency range will require three predetection filter bandwidth changes, a ratio of one-to-one and 5-to-one for band edges and a ratio of $2\frac{1}{2}$-to-one for midranges. When operating with a storage time of 10 seconds two additional predetection filter bandwidth choices must be available as indicated by Table II. One a ratio of $7\frac{1}{2}$-to-one (instead of 8) which results in the acceleration coverage shown and a second having a ratio of 15-to-one to extend the coverages, if desired, although with a slight detection loss. This means that a total of five predetection filter bandwidths located at the analyzer must be selectable at the remote control point.

The post detection filter bandwidth is optimized for radar pulse length and shape. Since three pulse lengths corresponding to prfs of 161, 80, and 40 cps are possible, a choice of three post detection filter bandwidths must be available under remote control.

Whenever a change in predetection bandwidth (change in resolution) or a change in storage time occurs the amplitude of the acceleration modulation of all acceleration gates will also have to be changed to bring the acceleration coverage to the desired values. This may be accomplished by remotely controlling the output amplitude of the acceleration sawtooth generator with a step attenuator. All acceleration gates receive this signal; hence, all are controlled simultaneously.

The repetition period of the acceleration sawtooth generator must equal the storage sampling period. This change must be accomplished remotely. Output sawtooth amplitude must remain constant for all periods, also the starting frequency of the oscillator sweep should remain fixed.

The cycle period of the 300 commutated gates should be half that of the storage sampling period to insure two samples per range bin. The cycle period should be remotely controllable.

The velocity function generator provides a staircase waveform having a step period of $\frac{1}{161}$ second and a staircase period of about 2.0 seconds as determined by a prf of 161, 185 velocity bins, 1.5 samples per bin, and flyback time. This waveform drives the velocity sweeps of the displays as well as velocity modulating the oscillators of all acceleration gates. The step and staircase periods remain constant for all prf's. The extent of the frequency modulation of the oscillators for a 10-second storage time, a prf of 161, a doppler span of 6 to 80 cps is 220 to 3000 kc and for a storage time of 2½ seconds 55 to 745 kc. The upper frequency limit of each of these spans is to be divided by two each time the prf is reduced by a factor of two. This reduction can be effected by dividing the waveform amplitude correspondingly with fixed dividers. Since this waveform drives all acceleration gates only a single control is required. This control should be remotely adjustable. The low frequency limit of each oscillator frequency sweep must remain fixed for all three frequency spans.

Even though the velocity scan is reduced for lower repetition rates, it is desirable for acceleration readout to maintain the input video bandwidth to the analyzers at 40 to 3000 kc.

Two separate contiguous bandpass filter sets are required, one to cover the 160 to 3000 kc range and the second to cover 40 to 745 kc. Each range will be covered by ten bandpass filters overlapping at their 3 db points. Frequencies below 160 kc and 40 kc are blocked to attenuate harmonics of the storage sampling repetition rate. A more complete description is given elsewhere. The first set is required when a 10-second storage is used and the second set is required with 2½ second storage. The set in use should be remotely determined.

The horizontal and vertical scales of the displays change with many of the parameters just discussed. Scale changes should be indicated automatically.

When many operating conditions must be properly set up, even though the controls are centrally located, a comprehensive mode of operation table should be prepared as an aid for the radar operator. Table I and II are incomplete examples of such a table. In other words the table should answer questions such as: for a given acceleration coverage and operating frequency what storage time, predetection filter bandwidth, etc., should be switched into the system? Consideration should be given to the possibility of automating as many of the control functions as possible.

Storage readout has been assumed to be real time, that is an echo signal was assumed to possess its true pulse width. However, if a slowed-down readout of storage is employed stretching pulse widths, then certain factors previously discussed will have to be scaled accordingly.

<u>Acceleration Gate Test Equipment</u> - A test video signal generator (to simulate the stored signal input to the system) shall be included as part of the overall system. It shall provide a signal of known amplitude adjustable over a 100 db range that may be modulated or manually tuned

over the input frequency range that the system must operate, and may also be combined with white noise of adjustable amplitude and of bandwidth essentially the same as the analysis input bandwidth. The signal shall be adjustable in prf, adjustable in pulse width, and adjustable in time delay to cover the full range of system design capabilities. It shall also be adjustable in range rate and acceleration and be capable of acceleration modulation that may represent either linear or non-linear range rate vs time characteristic.

A wide band frequency discriminator is necessary to display instantaneous frequency on an oscilloscope. The linear portion of the discriminator characteristic will cover a frequency range equal to or greater than the frequency range of the modulated oscillators of the acceleration gate system. The discriminator output must simultaneously respond to the very slow range rate sweep rate and to the more rapid acceleration sweep rates. Since d-c coupling will undoubtedly be necessary, the discriminator should also **respond** to a constant frequency input. Linearity should be within $\pm$ 1% of a straight line function for all frequencies within the modulated oscillator operating range. Precise amplitude limiting ahead of the discriminator shall make it insensitive to normal input levels that will exceed 1 volt peak to peak.

The discriminator display oscilloscope requires d-c amplification plus a high frequency response that will pass the acceleration function waveshapes. A large CRT of approximately 14 inches is desired and it shall be visible when adjusting the function generators to their starting frequency and slopes.

A monitor oscilloscope with suitable switching will serve as a check on various waveforms for periods and amplitudes. Among the signals to be monitored will be input signal level, signal limiting level, all generated sync signals, display sweep waveforms, and video amplifier output. This oscilloscope must be separate from the discriminator display since both will be used at the same time on occasion. The monitor oscilloscope may be a standard commercial make rack mounted unit that has a dc to 10 Mc bandwidth and a calibrated time base sweep. A tube size of 3 to 5 inches is adequate. A dual phosphor, one of long persistence, will be useful to monitor slow sweep rates.

OPERATOR AIDS

The planned radar is capable of acquiring very considerable information. Manual handling of the data requires selection of some data with loss of the remainder, except where the excess is preserved for later study. An increase in data rate beyond some manual phase would require operator aids. Operator aids can include computer techniques, storage means or a combination thereof.

The importance of this area cannot be overestimated. Even though the coverage problem was mentioned in the subtitle material AZIMUTHAL COVERAGE - OPERATING FREQUENCY under the heading SYSTEM DESIGN PHILOSOPHY, it is important to detail the coverage at this time to insure the maximum utility of the aids provided.

The Coverage Problem - Reference is made to Fig. 14. The sector to be covered is taken as 150°; with an antenna beamwidth of 10° this gives 15 angular (azimuthal) sectors. The basic range element is taken as a radial length of 500 n. mi., there being three such range elements to cover the required 500 to 2000 n. mi. range span.

Coverage of a particular 500 n. mi. element is achieved by selection of frequency, repetition rate and blanking. This idealized and simple approach is practical for a great deal of the time, and it provides a basis for exploring coverage methods. In securing a search of range from 500 to 2000 n. mi. three operating frequencies may be required.

For the interval from 500 to 1000 n. mi. E-layer refraction is preferred whenever possible. This requires low frequency radiation at low vertical angles between 10° and 2°. At times when it is impossible to use the E-layer, the largest of vertical radiation angles will be required to secure illumination via F-layer; vertical angles between 30° and 10° are examples. Vertical angles up to 40° can be required for short-range illumination via the F-layer when it is high. Thus for the first range interval of 500 to 1000 n. mi., a frequency giving good illumination will be selected on the basis of interpretation of local vertical and oblique soundings. For the designated range an 81-pps repetition rate with the first 500 n. mi. blanked out furnishes an appropriate mode of operation. The likelihood of "second time around" targets can be estimated from the oblique soundings and reduced by proper frequency selection.

In covering the interval between 1000 and 1500 n. mi. a frequency would be selected that gives illumination starting just before 1000 n. mi. A 53-pps repetition rate with the first interval blanked out would be appropriate. Vertical radiation angles required would run between 15 and 10° generally.

The frequency selected for 1000 to 1500 n. mi. could give coverage on out to 2000 n. mi. at times. However, illumination to 2000 n. mi. will be difficult and frequently impossible on a one-hop basis, and a separate higher frequency may be used to maximize far range coverage. The lowest of radiation angles will be required. When the oblique sounding shows scatter starting beyond 1000 n. mi. the higher repetition rate, 81 pps, can be used.

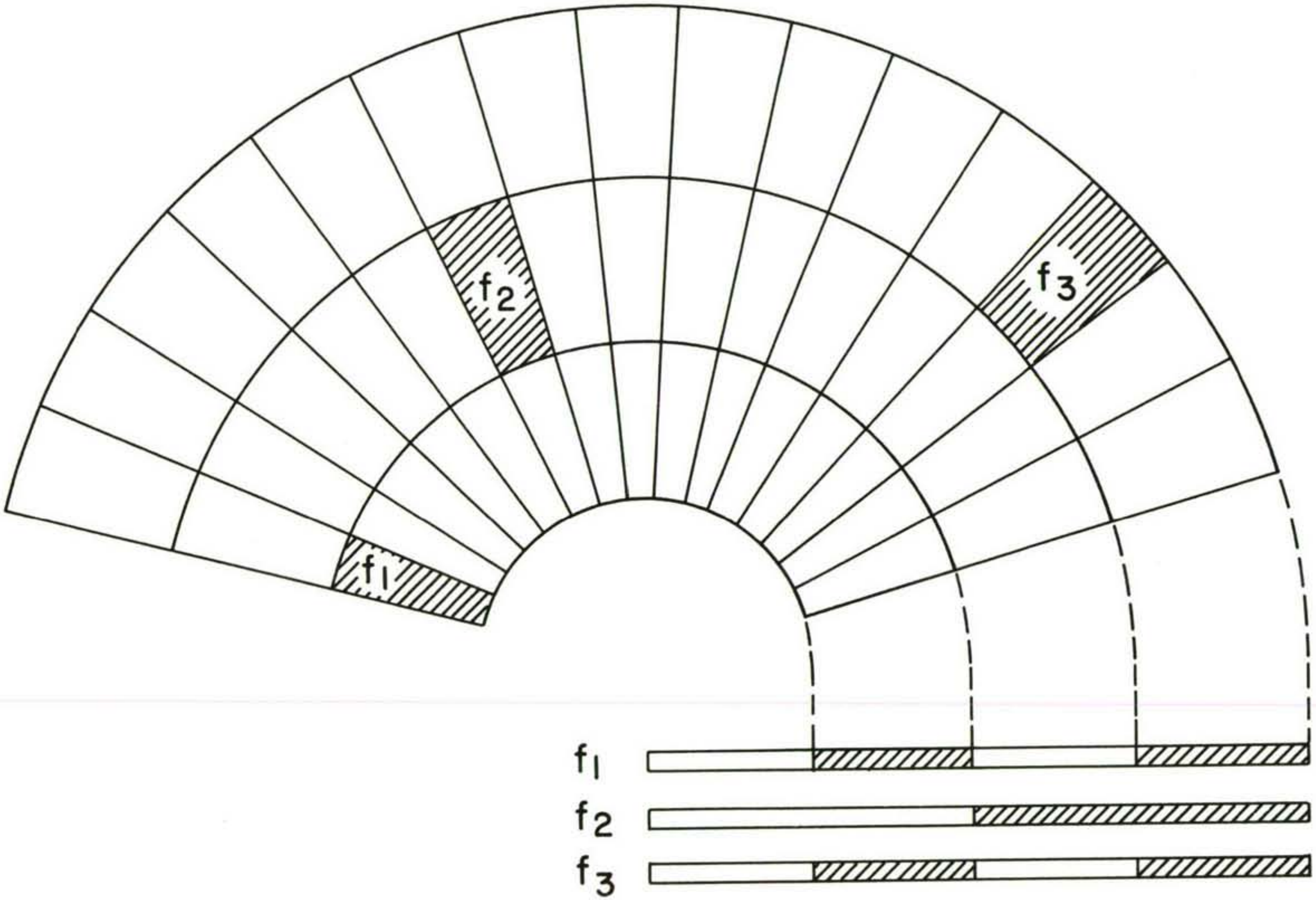


Fig. 14 - Possible azimuth-range sectoring by frequency and repetition rate selection

It can be seen that heavy reliance must be placed upon oblique soundings in determining the frequencies to be used, in selecting the vertical antenna steering, and in evaluating the adequacy of illumination. Further, knowledge of the effective illumination will allow use of high repetition rates with no range ambiguity.

Returning to the postulated coverage problem after the above excursion into methods, the number of sub-areas for 150° with 10° divisions and 1500 n. mi. with 500 n. mi. divisions is 45 as shown by Fig. 14. Table III is intended to explore search time requirements.

Table III

Dwell Time per sub-area	Total survey time using one trans.	Total survey time using two trans.	Total survey time using three trans.
3 min	135 min	68 min	45 min
1 min	45 min	23 min	15 min
3 sec	135 sec	68 sec	45 sec
1 sec	45 sec	23 sec	15 sec

Thus, with one transmitter more than two hours would be required for an aircraft population count when dwelling for 3 minutes on a sub-area. Even with the shortest tabulated dwell time and three transmitters the time coverage is not adequate for missile detection in all areas. For complete missile coverage and assuming detection capability adequate if it permits detection of burning targets in the ionosphere, the 600 kw average could be broken down into 12 units of 50 kw each. Then 12 sub-areas could be surveyed simultaneously and coverage improved by a factor of 12. This mode of operation should be made possible. Another mode of operation that is required is that of searchlighting one or more sub-areas continuously while carrying on an aircraft population count over the total area.

It is considered desirable to be able to search the sub-areas on a random pattern and that when a random frequency agility movement around the normal required frequency mode is employed it should be integrated with the search pattern.

In review, the search pattern should be flexible, running from a very deliberate population count using all transmitted power to illuminate one sub-area at a time to simultaneous illumination of up to 12 sub-areas. This latter can require operation upon 12 different frequencies and with 12 different antenna beams - all at the same time.

Equipment Aids - A set of master displays should be provided to aid the command to assess the data. These means should include a wall-type display of the number of targets in an antenna beamwidth and range block sorted as to speed and rough direction. An example of this type of display is shown in Fig. 15. This display shows a standard on which to base judgment alongside the latest available count.

Another wall-type display that should be included is one which will show all time-range tracks of critical aircraft. Consideration should be given to superimposing these tracks on a map of the area covered. A third large display feature should be considered for the radar output during missile detection operations. Speed and selected speed-time displays should be available.

Consideration shall be given to supplying computer means to extract the over-the-ground position from the slant radar range and ionogram information furnished by the local vertical sounder. Also the information on vertical angles shall be used to compute the vertical angle of arrival and thus correct the observed radial velocity to true radial velocity. The computer means might also keep general account of the aircraft in any azimuth-range tracking operation. For this purpose consideration should be given to automatically obtaining the data from the radar output. This would require the operator to set the threshold of signals to be read out on the basis of observed conditions.

Suggestions are solicited as to aids to determine the true azimuth and true ground position from the radar azimuth and radar slant range. It is realized that information as to true azimuth-range can be obtained from known HF broadcasting stations. Over-the-ground range can be also determined from the position of known airports. Propagation conditions can be determined from the backscatter soundings and from vertical soundings. Any display or computational aid which may help the operator select the best frequency and resolve the unknown factors will be considered.

There is a requirement to translate the radar data into some communications format for transmission to some distant point where the wall-type master display may be duplicated. These data are to be microwave linked to a nearby communications center and the quantity of data determines the capabilities of the link required.

BACKSCATTER SOUNDER

This backscatter sounder employs the antenna and transmitter of the system and will display the range of ground backscatter as a function of frequency. The unit about to be described is one way of performing the operation in approximately 15 seconds for each beam.

As Fig. 16 shows, a 100 kc oscillator triggers a blocking oscillator which generates a 10-nanosecond pulse of approximately $\cos^2$ shape, the amplitude-frequency spectrum of which is almost flat to 40 megacycles. This pulse feeds a filter which is 1 megacycle wide and is step tunable

[redacted]

	290°		300°		310°		320°		330°		340°		350°		0°		10°		20°		30°		40°		50°		60°		70°
Range - 1500 - 2000 Miles																													
Date	4-16	4-17	4-16	4-17	4-16	4-17	4-16	4-17	4-16	4-17	4-16	4-17	4-16	4-17	4-16	4-17	4-16	4-17	4-16	4-17	4-16	4-17	4-16	4-17	4-16	4-17	4-16	4-17	
Time	1859	1858	1856	1855	1853	1852	1850	1849	1847	1846	1844	1843	1841	1840	1838	1837	1835	1834	1832	1831	1829	1828	1826	1825	1823	1822	1820	1819	
Approach																													
300+	6	5	10	4	5	6	2	2	7	5	5	9	5	1	4	6	3	9	8	6	1	3	8	0	5	9	1	15	
200 - 300	9	7	15	0	11	2	15	6	9	9	9	2	5	9	7	18	9	9	12	2	7	7	18	1	5	11	1	19	
100 - 200	9	13	9	19	0	9	1	2	9	9	9	0	6	6	5	8	6	7	9	6	5	8	9	13	1	11	7	18	
Recede																													
300+	5	9	9	7	9	7	5	7	5	2	0	2	1	9	13	5	1	9	9	3	6	5	0	11	1	11	18	6	
200 - 300	7	8	3	15	6	19	7	2	3	2	5	2	7	6	0	9	6	9	14	0	13	5	11	3	8	16	9	1	
100 - 200	8	8	5	19	7	9	8	9	3	3	5	5	0	6	16	5	0	7	7	2	6	6	17	9	11	7	1	3	
Total	44	50	51	64	38	52	38	28	36	30	33	20	24	37	45	45	25	50	59	19	38	34	63	37	31	65	37	62	
Range - 1000 - 1500 Miles																													
Date	4-16	4-17	4-16	4-17	4-16	4-17	4-16	4-17	4-16	4-17	4-16	4-17	4-16	4-17	4-16	4-17	4-16	4-17	4-16	4-17	4-16	4-17	4-16	4-17	4-16	4-17	4-16	4-17	
Time	1859	1858	1856	1855	1853	1852	1850	1849	1847	1846	1844	1843	1841	1840	1838	1837	1835	1834	1832	1831	1829	1828	1826	1825	1823	1822	1820	1819	
Approach																													
300+	9	7	0	0	2	9	0	9	9	9	6	9	8	3	5	19	5	9	0	7	2	2	8	7	0	6	9	1	
200 - 300	8	6	9	9	0	0	5	3	5	2	5	9	3	0	3	15	7	8	4	3	9	5	1	0	6	8	11	7	
100 - 200	9	9	0	9	3	0	2	3	9	5	7	5	7	19	0	0	5	7	7	5	5	7	1	4	7	2	16	2	
Recede																													
300+	6	9	0	9	9	2	3	7	5	9	7	6	6	3	8	17	1	7	5	8	1	1	18	4	9	2	11	0	
200 - 300	6	5	3	0	9	3	9	7	7	5	0	0	3	1	8	5	5	8	1	6	9	3	1	5	8	6	11	1	
100 - 200	7	7	0	5	5	2	0	2	5	7	3	3	0	.2	7	9	7	1	9	14	3	0	6	0	7	7	19	7	
Total	45	34	12	32	28	16	19	31	40	37	28	37	27	28	31	65	30	40	26	43	29	18	35	20	37	31	77	18	
Range - 500 - 1000 Miles																													
Date	4-16	4-17	4-16	4-17	4-16	4-17	4-16	4-17	4-16	4-17	4-16	4-17	4-16	4-17	4-16	4-17	4-16	4-17	4-16	4-17	4-16	4-17	4-16	4-17	4-16	4-17	4-16	4-17	
Time	1859		1856	1855	1853	1852	1850	1849	1847	1846	1844	1843	1841	1840	1838	1837	1835	1834	1832	1831	1829	1828	1826	1825	1823	1822	1820	1819	
Approach																													
300+	8	5	9	0	9	17	5	0	5	6	4	19	7	5	19	3	9	2	6	0	6	8	3	4	8	6	11	13	
200 - 300	9	13	9	0	0	9	17	9	7	5	5	13	3	1	1	7	1	4	16	2	0	6	15	2	9	5	16	1	
100 - 200	9	6	0	3	9	13	3	9	0	9	4	2	2	16	9	17	3	4	8	7	0	8	10	10	7	13	6	2	
Recede																													
300+	6	9	0	5	9	9	2	5	0	6	12	1	3	0	11	3	4	8	2	3	8	0	11	2	3	14	7	1	
200 - 300	7	6	1	0	1	2	9	9	6	0	2	0	2	0	0	3	9	6	1	5	1	14	0	1	1	4	16	4	
100 - 200	7	9	2	1	8	9	0	2	0	3	15	5	2	5	10	1	4	5	6	8	6	6	8	9	5	7	0	3	
Total	46	48	21	9	36	59	36	34	18	29	42	40	19	27	50	34	30	29	41	25	21	42	47	28	33	49	56	24	
TOTAL	135	132	84	105	102	127	129	103	94	96	103	92	70	92	126	144	85	119	126	87	88	94	145	85	101	145	170	104	T5581516
500																													

Fig. 15 - Wall type display with examples of some important data on view. This figure emphasizes the aircraft counting routine, though missile information could appear in certain sectors.

[redacted]

[redacted]

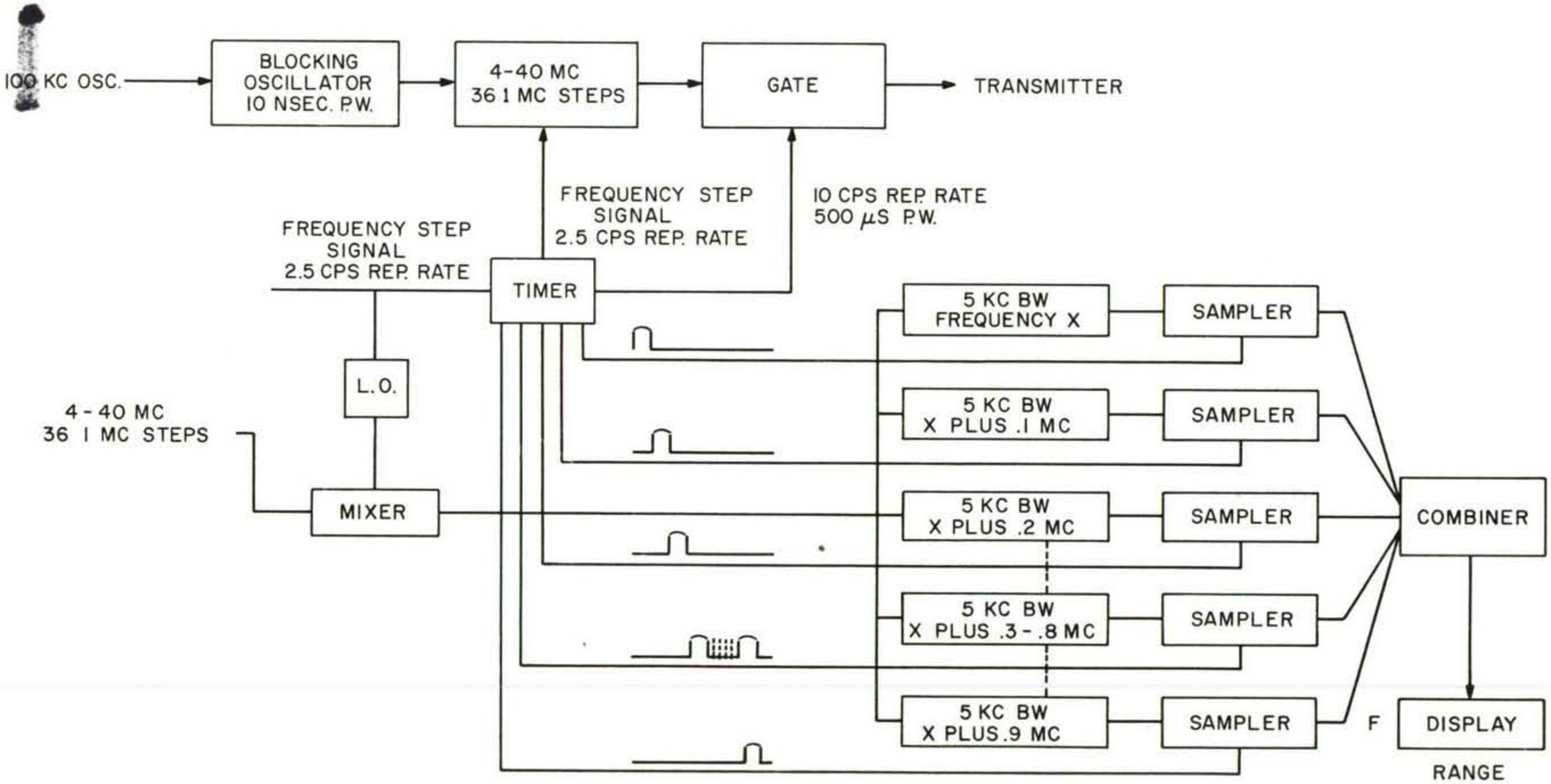


Fig. 16 - Block diagram of backscatter sounder

[redacted]

from 4 to 40 megacycles at 2.5 steps per second. The filter output feeds a gate whose output is gated at 10 pulses per second by a 500 μsecond wide pulse. This then feeds the exciter chain of the system transmitter.

The received output from the antenna and duplexer is fed to another 1-Mc wide filter which is step tunable from 4 to 40 megacycles and steps in synchronism with the transmitted frequency filter. An oscillator of appropriate frequency is also step tuned so as to produce the i-f frequency at the output of the mixer. The mixer feeds a band of 10 crystal filters of 5 kc bandwidth about center frequencies of 1 F, 1 F + 100 kc, 1 F + 200 kc, etc. This will give 10 outputs that after 10 suitable amplitude detectors can be fed to 10 samplers where they are sampled in succession by 20 μsecond pulses. These pulses are then fed into a combiner and to the intensity grid of a storage tube.

The horizontal sweep of this tube is a 10-cycle-per-second sawtooth wave. The vertical sweep of this tube is a combination of two staircase functions. One of these staircases has steps up every 20 μseconds, in synchronism with the sampler described above, for a total of 10 steps and then returns to the beginning and repeats every 200 μseconds. The second staircase has a step amplitude of 10 times the step amplitude of the first staircase and steps 2.5 times every second in synchronism with the stepping of the 1-megacycle bandwidth filter. This staircase has a total of 36 steps thus allowing the display of the backscatter from 4 to 40 megacycles.

The system should be capable of being stopped at any time after initiation so that no unnecessary time will be wasted in surveying frequencies for which there is no backscatter.

The 4 to 40 megacycle range is presumed and any proposal should match this frequency range.

STANDARD FREQUENCY SOURCES

The proposed system calls for standard frequency sources and consequently means to check these sources from external LF and HF transmissions. The standard frequency sources should have an accuracy of one part in 10^9 or better.

TEST EQUIPMENT

Efficient operation of the system requires adequate captive test equipment dispersed throughout the system as well as mobile test equipment deemed necessary for successful operation. This equipment should include the lists appended to this document. In addition certain mechanical and electrical tools are to be considered part of the desired system.

PORTABLE TEST EQUIPMENT

The portable test equipment, some of which is applicable to the measurement facility, include those of the following manufacture or their equivalent.

(a) Therm-O-Meter
  1 - Simpson Model 388

(b) Q-Meter
  1 - Boonton Radio Corporation, Type 260A
  16 - Plug-in standard inductors for above

(c) HF Transmitter - 2 to 30 mcs at 100 watts
  1 - Johnson CDC

(d) Volt-Ohm-Milliameters
  4 - Triplett Model 630-PL

(e) Dummy Loads
  12 - Termaline Coaxial Load Resistors, 5-watt series, Bird Model 80-M
  1 - Sierra Model 185A-100FN Dummy Load
  20 - Weinschel Model 535 MN Terminations

(f) Oscilloscope Camera
  1 - Tektronix C-12 with mounting bezel and 4 X 5 Graflex back

(g) Constant - Amplitude Signal Generator
  1 - Tektronix Type 190B

(h) Megacycle Meter (Grid Dip Meter)
  1 - Measurements Corp. Model 95

(i) R.F. Voltmeter
  2 - H.P. Model 410B VTVM
  2 - H.P. Model 11042A Probe Coax T Conn.
  2 - H.P. Model 11043A Probe Coax N Conn.
  2 - H.P. Model 11040A Capacitive Voltage Divider

(j) Power Meter
  1 - H.P. Model 430C Power Meter
  1 - H.P. Model 477B Thermistor Mount

(k) Strobotac
  1 - G.R. Type 1531-A Electronic Stroboscope

[redacted]

(l) RX Meter
- 1 - Boonton Radio Corp. Type 250A
- 1 - Boonton Radio Corp. Type 515-A Adapter Kit

(m) Phase Meters
- 1 - Ad-Yu Type 205A, 2 with indicator
- 1 - Ad-Yu Type 205B1 with Unit A Detector (15 Mc-60 Mc)
- 4 - 3 db Attenuators Weinschel Model 50-3

(n) Phase Sequence Indicator
- 1 - General Electric Cat. No. 5467032G5

(o) Wheatstone Bridge
- 1 - Gray Instrument Company Model E-3107

(p) High Potential Tester
- 1 - Sorensen Model 1060-5 or Model 2060-50

(q) R.F. Impedance Bridge
- 1 - G.R. Type 1606-A
- 6 - G.R. 874 to BNC Jack Type 874-QBJA
- 6 - G.R. 874 to N Jack Type 874-QNJA
- 6 - G.R. 874 to UHF Jack Type 874-QUJ
- 2 - G.R. 874 to LC Jack Type 874-QLJA

(r) Clamp-On Ampmeter
- 1 - Amprobe Model RS-300
- 1 - Amprobe Model 1200

(s) Variable Attenuators
- 2 - H.P. Variable Coaxial Ateenuator Model 355C
- 2 - H.P. Variable Coaxial Attenuator Model 355D
- 2 - Weinschel Model 905 Continuously Variable

(t) H.F. Signal Generators
- 1 - H.P. Model 606A
- 1 - H.P. Output Termination Model 11507A

(u) General Purpose Oscilloscope
- 1 - Tektronix Model 545A
- 1 - Tektronix Type C-A Dual-Trace Plug-In
- 1 - Tektronix Type L Fast Rise Plug-In
- 1 - Tektronix Type M Four Trace Plug-In
- 1 - Tektronix Type 500153A Mobile Cart
- 6 - Tektronix Type P6003 Probe
- 1 - Camera Bezel
- 1 - Viewing Hood

(v) Tube Tester
- 2 - Hickok Model 752A

(w) Audio Oscillator
- 1 - H.P. 200 CD Audio Oscillator

(x) Pulse Generator
- 1 - H.P. Model 212A Pulse Generator

(y) Wave Analyzer
- 1 - H.P. Model 302A Wave Analyzer
- 1 - Sierra Model 125B
- 1 - Sierra Model 158A

(z) Function Generator
- 1 - H.P. Model 202A

(ba) Sweep Frequency Generator
- 1 - Jerrold Model 707-1
- 1 - Jerrold Scope Preamplifier

(bb) Spectrum Analyzer
- 1 - Panoramic Model SSB-3a

(bc) Radio Receiver
- 1 - Hallicrafters

(bd) R.F. Power and VSWR Instrument
- 1 - M.C. Jones Model 263

(be) Field Strength Meter
- 1 - Ferris Model 32D Noise and Field Strength Meter or Stoddart Field Strength Meter (3 - 30 Mcs and VHF range)

(bf) Ampere Meter
- 1 - 1500 ampere precision current meter and short

(bg) Voltmeters
- 1 - 7.0 V.D.C. Midscale zero reading precision voltmeter

(bh) Termination
- 12 - Tektronix Model 011-055 75 ohm termination
- 12 - Tektronix Model 011-049 50 ohm termination
- 12 - Tektronix Model 011-056 93 ohm termination

(bi) Decade Boxes

2 - Aerovox Model ARD-15 0-110 ohm
2 - Aerovox Model ARC-23 0-11 k ohm
2 - Aerovox Model ARD-31 0-1.1 Meg. ohm
2 - Aerovox Model ACD-13 0-.011 ufd
2 - Aerovox Model ACD-23 0-1.1 ufd
2 - Aerovox Model ACD-33 0-10.0 ufd
1 - Aerovox Model ALD-12 0-10 mh
1 - Aerovox Model ALD-22 0-100 mh
1 - Aerovox Model ALD-32 0-1.0 hy
1 - Aerovox Model ALD-42 0-10.0 hy

(bj) Voltmeters
1 - H.P. Model 400D Vacuum Tube Voltmeter
1 - H.P. Model 412A Precision D.C. Voltmeter-Ohmmeter-Ammeter
1 - Ballantine Model 320 Vacuum Tube Voltmeter
1 - Ballantine Model 340 Vacuum Tube Voltmeter

(bk) Frequency Meter and Discriminator
1 - G.R. Model 1142A

(bl) Oscillators
500 Kc Variable Frequency Crystal Oscillator
500 Kc Variable Frequency Oscillator ± 4 Kc and ± 50 Kc Crystal Oscillator, 25 position

(bm) Power Supplies
1 - Lambda Model 71
1 - Lambda C-881M

CAPTIVE TEST EQUIPMENT

The electronic complex must be provided with built-in test equipment at key points to insure good operation and maintenance of the system. This equipment must include:

(a) 1 standard time receiver in VLF

(b) 1 standard time receiver in HF

(c) 1 RM15 Tektronix Oscilloscope as receiver(s) monitor to be part of the display console

(d) 1 RM545 Tektronix Oscilloscope to monitor index timing and system synchronization

(e) 1 RM15 Tektronix Oscilloscope to monitor storage playback

(f) H.P.A. Control Console - power and wave form monitor scope, Tektronix Model RM45A Oscilloscope

(g) Receiver Monitor Panel - signal level and backscatter monitor, Tektronix Model RM-15 Oscilloscope

(h) Exciter and pulse generator cabinets - exciter and pulse generator shape and level monitor - Tektronix Model RM43 Oscilloscope

(i) Target Simulator Cabinet - target simulator frequency generator - H.P. Model 200-I Audio Oscillator, Noise generator, Scott type 811-A, Random noise generator

(j) Frequency Standard Rack - Frequency Standard 100 Kc and 1 Mc - James Knight Model FS-1100T Frequency Standard and power supply

(k) Recorder Cabinets - Audio frequency standard - Specific Products Model SR 7R WWV Receiver with CHU

(l) Recorder Patch Panel - Recorder Signal Level Monitor - Tektronix Model RM-15 Oscilloscope

(m) Pulse Amplifier - 2 each G.R. Type 1219-A Unit Pulse Amplifier

(n) Exciter and Pulse Modulator Cabinets - Electronic Counter - H.P. Model 524-B, Electronic Counter with Model 525-A Frequency Converter Unit and Model 526-B Time Interval Unit

GOVERNMENT-FURNISHED INFORMATION AND EQUIPMENT

The Rome Air Development Center (RADC) will elaborate on the Government Logistic Support which is available in transportation, including MSTS and MATS, material handling, housing and messing facilities, recreation, etc.

In the area of communications, RADC will detail the government communications facilities available to the eventual contractor(s) who fabricate and install the FPS-95.

There are related projects and facilities which must dovetail with the operational FPS-95. The inputs from these related programs will be supplied by RADC.

The cost breakdown requested subsequently should be adhered to because some items may become GFE and thus readily removed from contract costs.

SPARES

The question of spares for a foreign installation is a formidable one. Duplicate key units and components must be provided for ready change to keep the station in operation. The use of standard, regulated power supplies of similar make is recommended wherever applicable and the remark on spares applies to both captive and portable test equipment as well. A detailed listing of costs for tubes, circuit elements, and system component elements is required to assist in evaluating the adequacy of spares treatment.

STUDY REQUIREMENTS

ENGINEERING AND COST SERVICES

In the main the study requirements include engineering and cost services to provide company state of the art design and construction information on an operational prototype of a very long range HF radar. Some of the details are interspersed in the work statement specification under components.

The study contractors shall report on the expected performance of the components integrated into a system capable of being transported to and erected at some foreign location. The Naval Research Laboratory has a wealth of operating experience with the MADRE radar and they should be consulted where the contractor's experience is lacking. In any event, that proposed by the contractor must show special regard for the following factors in primarily a one-hop system:

(a) Range (radar slant and ground)

(b) Accuracy (range, azimuth, range rate, time, etc.)

(c) Problems expected in integrating the components into a system

(d) Vulnerability to ECM, both jammer and repeater types

(e) Flexibility of antenna-transmitter scan to allow increased information rate and to provide more capability for ESV and missile launch detection

(f) Provisions for growth

(g) Planning in connection with an overseas location specified by the government. This planning shall include planning requirements for:

(1) Site surveying

(2) Training of installtion personnel

(3) Liaison work with building designers and major commands

(4) Manning

(5) Interface problem with others involved

(h) Environmental conditions affecting equipment design:

(1) Contractors knowledge and study of the ionosphere as a refracting medium over 24-hour periods in the next eleven-year cycle of expected operation (1967-1978)

(2) External noise and local noise; electromagnetic compatibility

(3) E-layer and sporadic E

(4) Problems of ionospheric absorption

(5) False echoes, internally generated system targets

(6) Effects of splitting of echoes; double refraction and polarization

(7) Focusing effects

(8) Severe bending (skewing) of radiation from its expected path resulting in coverage of an area different from that expected with the resultant possibility of gaps in coverage

(9) Simultaneous one-hop and two-hop transmission caused by spread of beam in vertical plane

(10) Simultaneous reflection of signals by two ionosphere layers at different heights

(11) Clutter spectrum

(12) Siting criteria

(13) Operating frequency agility as a means to provide improvement in ECM rejection, interference reduction, detectability, etc.

(14) Bore-siting capability on known stations to determine deviation of incoming azimuth angle from true bearing

(15) Safety features

GENERAL RELIABILITY

The electronic equipment must be capable of around-the-clock operation, day after day if need be, and thus the component quality, mode of construction, necessary spares, and construction serviceability should be considered from two angles as these affect cost.

First let it be assumed that the prototype operational radar will have electronic components and construction equal to or better than good commercial practice and that the electronic equipment will be housed in a controlled atmosphere environment. In addition let it be assumed that commercial documentation and drawings of sufficient detail for manufacture and maintenance are adequate, with operation and maintenance a hired operation.

Secondly let it be assumed that operation and maintenance is a hired operation and that the specifications for the components and overall equipment are prepared in accordance with MIL-S-6644 of the issue in effect on the date of invitation to bid and that the contractor shall, in addition, use the following specifications for guidance in determining costs of all components.

(a) MIL-E-4158

(b) MIL-R-9673

(c) MIL-M-26512

(d) MIL-R-27055

(e) MIL-R-27070

(f) MIL-R-27542

(g) MIL-E-4682C

(h) MIL-D-9412D - Appendices A, B and H

Guidance on the applicable areas of the above specifications will be supplied by RADC.

TECHNICAL REPORT

Fifty (50) copies of a technical report shall be furnished for the proposed system. The technical report shall be prepared in accordance with Air Force Systems Command Manual AFSCM 5-1, dated 1 November 1961.

[redacted]

[redacted]

ECONOMIC AND SCHEDULE COMPARISONS

The contractor shall report the technical, economic and schedule comparisons (which have led to the chosen design) in an adequate manner so that independent review can be performed.

COST AND DELIVERY

The contractor shall study and report the costs and delivery schedules of an overall integrated equipment based on these components and report these separately from the technical data. Phase II desired delivery is 21 months after contract signing. The accompanying cost breakdown schedule provided by this document includes the breakdown details. Two complete cost analyses will be prepared for cost trade-offs. One analysis will be based on costs for good commercial practice with equipment operated in a controlled atmosphere. The other will be based on applicable specifications, mentioned previously, as these are delineated in importance by RADC. The type of packaging used in determining costs must be indicated in each instance.

COST CHART

The cost chart, Fig. 17, is detailed and combination of elements is permitted in costing provided a statement is made as to what elements are represented in the combined cost.

BIBLIOGRAPHY

The attached bibliography contains information on NRL MUSIC Radar, NRL's MADRE Radar and NRL's High Power MADRE Radar. The list contains reports on equipment features as well as operating experience with the detection of aircraft, missiles, atomic events, satellites and the moon. Some of these reports may be in company files, Astia, or available at the Naval Research Laboratory.

ACKNOWLEDGMENT

The authors wish to acknowledge the technical assistance and guidance in the preparation of this document of J.L. Ahearn, J.R. Davis, Dr. R.C. Guthrie, W.C. Headrick, M.S. Lieberman, J.E. McGeogh, I.H. Page, D.C. Rohlfs, G.A. Skaggs, Mrs. C.B. Tesauro, C.L. Uniacke, F.H. Utley, J.H. Veeder, E.W. Ward, Mrs. M. Martin, Mrs. M. Etzel and Mrs. R. Roland all of the Naval Research Laboratory; and Mr. J. Fallik and staff of the Rome Air Development Center.

[redacted]

[redacted]

	COSTS OF SYSTEM COMPONENTS PACKED FOR SHIPMENT FOB MANUFACTURER'S PLANT(S)			
	Good Commercial Practice in Controlled Environment	Costs Under MIL Specs as Modified by RADC	OVERSEAS ERECTION AND CHECK-OUT COSTS	ESTIMATED WEIGHTS AND PROPOSED METHOD OF SHIPMENT
ANTENNA(S)				
Beam Forming Matrices (Switching, etc.)				
DUPLEXER(S)				
TRANSMITTER(S)				
Drivers				
MASTER FREQUENCY PROGRAMMER & SELECTOR				
RECEIVER(S)				
Comb Filters				
Approach-Recede Filters				
60 db Dynamic Range Processing				
BACKSCATTER SOUNDER				
VERTICAL SOUNDER AND ANTENNA				
TEST EQUIPMENT				
DISPLAYS				
ACCELERATION GATES AND DISPLAYS				
OPERATOR AIDS				
SPARES				
Antenna				
Transmitter				
Receiver				
Test Equipment				
Auxiliaries				
STATION PLAN				
Buildings and Accessories				
Water System				
Sewage System				
Commissary				
Communications (Local)				
Communications (External)				
Fencing and Lighting				
Roads				
Guard Houses				
Power Plant and Distribution System				
Fuel Storage				
				OVERSEAS MAINTENANCE AND OPERATIONS FORCE
MANNING/12-HOUR SHIFT				

Figure 17

[redacted]

BIBLIOGRAPHY

1. Page, R.M., "Storage Radar," NRL Report 3532 (Secret Report, Unclassified Title), Oct. 1949

2. Boyd, F.E., and Cumings, R.G., "A HF Pulsed Transmitter for an Experimental Cross Correlation Radar System," NRL Report 4848 (Secret Report, Secret Title), Nov. 1956

3. Jensen, G.K. and Uniacke, C.L., "Investigation of the Graphechon Storage Tube," NRL Report 4134 (Unclassified) May 1953

4. Boyd, F.E., "The Coherence of Radar Echoes," NRL Report 4258 (Confidential Report, Unclassified Title), Dec. 1953

5. Ahearn, J.L., Jr., and Headrick, J.M., "Recording Radar Signals at Intermediate Frequencies," NRL Report 4611 (Unclassified) Aug. 1955

6. Jensen, G.K., and McGeogh, J.E., "An Active Filter," NRL Report 4630 (Unclassified) Nov. 1955

7. Headrick, J.M., and Ahearn, J.L., Jr., "An Analogue System for Computing Correlation Coefficients," NRL Report 4835 (Unclassified) Sept. 1956

8. Page, R.M., and George, S.F., "Magnetic Drum Storage Applied to Surveillance Radar," NRL Report 4878 (Confidential Report, Unclassified Title), Jan. 1957

9. Jensen, G.K., and Uniacke, C.L., "Spectral Bandwidth of Backscatter Signals," NRL Report 4976 (Unclassified) Aug. 1957

10. Jensen, G.K., and Gager, F.M., "Cross Correlation Electronic Storage Radar," NRL Report 5016 (Unclassified) Oct. 1957

11. Wyman, F.E., and Zettle, E.N., "Magnetic Drum Storage Cross Correlation Radar," NRL Report 5023 (Secret Report, Unclassified Title) Nov. 1957

12. Uniacke, C.L., and Jensen, G.K., "An Investigation of the Radechon Storage Tube," NRL Report 5201 (Confidential Report, Unclassified Title) Sept. 1958

13. Curley, S.R., Utley, F.H., and Guinard, N.W., " A Frequency Indicator for the Range 10-90 CPS," NRL Report 5187 (Unclassified) Sept. 1958

14. Uniacke, C.L., and Jensen, G.K., "A Frequency-Translation and Storage System Utilizing the Radechon Storage Tube," NRL Report 5238 (Confidential Report, Unclassified Title) Dec. 1958

[redacted]

15. Jensen, G.K., and Uniacke, C.L., "Performance Characteristics of the MUSIC Radar System," NRL Report 5247 (Secret Report, Unclassified Title) Dec. 1958

16. Uniacke, C.L., and Jensen, G.K., "The Storage System for Project MUSIC," NRL Report 5338 (Confidential Report, Unclassified Title) Aug. 1959

17. Uniacke, C.L., and Jensen, G.K., "Backscatter and Doppler Filters for the Project MUSIC Radar," NRL Report 5441 (Confidential Report, Unclassified Title) Feb. 1960

18. Uniacke, C.L., Jensen, G.K., Tesauro, C.B., and Veeder, J.H., "A Study of Ionosphere Disturbances with Project MUSIC Radar - 1 Sept 1957 to May 31, 1959," (Unclassified Title), "A Study of Missile-Induced Ionospheric Disturbances and Surveillance of the Atlantic Missile Range with the Project Music Radar from September 1957 to May 31, 1959," (Secret Title), NRL Report 5508 (Secret Report) 8 Aug. 1960

19. Uniacke, C.L., Jensen, G.K., and Veeder, J.H., "A Study of Ionosphere Disturbances with Project MUSIC Radar - June 1, 1959 to Oct. 31, 1959," (Unclassified Title), "A Study of Missile-Induced Ionospheric Disturbances and Surveillance of the Atlantic Missile Range with the Project MUSIC Radar from June 1, 1959 to October 31, 1959," (Secret Title), NRL Report 5511 (Secret Report) 19 Aug. 1960

20. Uniacke, C.L., and Jensen, G.K., "Circuits for the Operation of Project MUSIC Storage System," NRL Report 5399 (Confidential Report, Unclassified Title) 17 Nov. 1959

21. Jensen, G.K., Uniacke, C.L., and Zettle, E.N., "Quality of Radar Information as Influenced by an Ionospheric Propagation Path," NRL Report 5540 (Confidential Report, Unclassified Title) 12 Oct. 1960

22. Jensen, G.K., "An Improved Gate System for the MADRE Radar," NRL Report 5570 (Secret Report, Unclassified Title) Dec. 1960

23. Uniacke, C.L., Jensen, G.K., and Veeder, J.H., "A Study of Ionospheric Disturbances with the Project MUSIC Radar from November 1, 1959 to January 31, 1960," (Unclassified Title), "A Study of Missile-Induced Ionosphere Disturbances and Surveillance of the Atlantic Missile Range with the Project MUSIC Radar from November 1, 1959 to January 31, 1960," (Secret Title) NRL Report 5564 (Secret Report)

24. McGeogh, J.E., Jensen, G.K. and Uniacke, C.L., "A 100-kc Quartz Crystal Comb Rejection Filter," NRL Report 5589 (Confidential Report, Unclassified Title) 16 Feb. 1961

[redacted]

25. Uniacke, C.L., Jensen, G.K., and Veeder, J.H., "A Study of Ionospheric Disturbances with the Project MUSIC Radar from February 1, 1960 to June 30, 1960," (Unclassified Title), "A Study of Missile-Induced Ionospheric Disturbances and Surveillance of the Atlantic Missile Range with the Project MUSIC Radar from February 1, 1960 to June 30, 1960," (Secret Title) NRL Report 5584 (Secret Report) Feb. 1961

26. Uniacke, C.L., Jensen, G.K., and Gager, F.M., "An Investigation of Ionospherere Disturbances with Project MUSIC Radar (1957-1958)," (Unclassified Title), "An Investigation of the Possibility of Detecting Nuclear Explosions Via an Ionosphere-Propagation Path, A Summary of the Plumbob and Hardtack II Series," (Secret Title) NRL Report 5585 (Secret Report) 24 Mar. 1961

27. Curley, S.R., Headrick, J.M., Morgan, G.A., and Utley, F.H., "High Frequency Radar Observations Made on Trailblazer 1G," NRL Memo Rpt 1176 (Unclassified) 1 June 1961

28. Headrick, J.M., Navid, B.N., Ahearn, J.L., Curley, S.R., Utley, F.H., Headrick, W.C., and Zettle, E.N., "A MADRE ICBM Detection," (Unclassified Title), "Some Trajectory Parameter Determinations when Employing Ionosphere Refraction," (Secret Title), NRL Memo Rpt 1251 (Secret Report) 1 Dec. 1961

29. Headrick, J.M., Curley, S.R., Ahearn, J.L., Headrick, W.C., and Utley, F.H., "MADRE Evaluation," (Unclassified Title), "The Detection of a Powered Missile's Transit of the Ionosphere (AMR Test 5462)," (Secret Title), NRL Memo Rpt 1287 (Secret Report)2 Jan. 1962

30. Headrick, J.M., Curley, S.R., Thorp, M.E., Ahearn, J.L., Utley, F.H., Headrick, W.C., and Rohlfs, D.C., "MADRE Evaluation Report III," (Unclassified Title), "Detection and Analysis of AMR Test 6210," (Secret Title), NRL Memo Rpt 1316 (Secret Report) 1 Feb. 1962

31. Headrick, J.M., Ahearn, J.L., Curley, S.R., Ward, E.W., Utley, F.H., and Headrick, W.C., "MADRE Evaluation IV," (Unclassified Title), "A Low Altitude Atlas Detection at Long Range," (Secret Title) NRL Report 5811 (Secret Report) 27 June 1962

32. Curley, S.R., Headrick, J.M., Ahearn, J.L., Headrick, W.C., Utley, F.H., Rohlfs, D.C., and Thorp, M.E., "MADRE Evaluation Report V," (Unclassified Title), "Detection and Analysis of Trailblazer 11A," (Secret Title) NRL Report 5824 (Secret Report) 27 July 1962

33. Headrick, J.M., Ahearn, J.L., Curley, S.R., Utley, F.H., Headrick, W.C., and Thorp, M.E., "MADRE Evaluation VI," (Unclassified Title), "Minuteman Skin and Exhaust Boundary Echoes," (Secret Title), NRL Report 5825 (Secret Report) 27 July 1962

34. Davis, J.R., Headrick, J.M., and Page, I.H. (Unclassified Title), "A System for the Extension of Unambiguous Radar Without Degradation of Velocity Information," (Secret Report) NRL Report 5849, Oct. 3, 1962

35. Gager, F.M., Headrick, W.C., Morgan, G.A., Utley, F.H. and Zettle, E. N., "MADRE Performance Part 1 - Very Long Range, Over-the-Horizon Detection of Aircraft with the MADRE Radar," (Secret Title) NRL Report 5862 (Secret Report) 31 Dec. 1962

36. Boyd, F.E., "Antenna Patterns of Array of Corner Reflectors Between 13 and 27 Mc," (Unclassified Title) NRL Report 5875 (Confidential Report) 3 Jan. 1963

37. Jensen, G.K., and McGeogh, J.E., "Development of a Gate System for the Improvement of the MADRE Radar, Part I - System Theory, Calculations and Planning," (Unclassified Title), "Development of an Acceleration Gate System for the Improvement of the MADRE Radar, Calculations and Planning," (Secret Title) NRL Report 5876 (Secret Report) 11 Jan. 1963

38. Curley, S.R., Headrick, W.C. Headrick, J.M., Utley, F.H., Ahearn, J.L., and Skaggs, G.A., "MADRE Evaluation Report VII," (Unclassified Title), "MADRE Evaluation VII - Detection of a Submarine-Launched Polaris Missile Via the E-Layer," (Secret Title) NRL Report 5881 (Secret Report) 22 Jan. 1963

39. Jensen, G.K., and McGeogh, J.E., "Development of a Gate System for the Improvement of the MADRE Radar, Part 2 - Development of Key Circuits and A Signal Simulator," (Unclassified Title), "Development of an Acceleration Gate System for the Improvement of the MADRE Radar, Part 2 - Development of Key Circuits and A Signal Simulator," (Secret Title) NRL Report 5899 (Secret Report) Feb. 1963

40. Gager, F.M., Headrick, W.C., Morgan, G.A., Rohlfs, D.C., Tesauro, C.B., and Zettle, E.N., "MADRE Performance Part 2 - Observations of Feb. 8, 1962," (Unclassified Title), "MADRE Performance Part 2 - Very Long Range, Over-the-Horizon Detection of Aircraft with the MADRE Radar," (Secret Title) NRL Report 5898 (Secret Report) 28 Feb. 1963

41. Jensen, G.K., and McGeogh, J.E., "Development of a Gate System for the Improvement of the MADRE Radar, Part 3 - Experimental Verification of System Theory by Means of the Signal Simulator and Key System Components," (Unclassified Title), "Development of an Acceleration Gate System for the Improvement of the MADRE Radar, Part 3 - Experimental Verification of System Theory by Means of the Signal Simulator and Key System Components," (Secret Title) NRL Report 5900 (Secret Report) Feb. 1963

42. Jensen, G.K., and McGeogh, J.E., "Development of a Gate System for the Improvement of the MADRE Radar, Part 4 - Laboratory Evaluation of the Complete System and Report of Recent Circuit Developments," (Unclassified Title), "Development of an Acceleration Gate System for the Improvement of the MADRE Radar, Part 4 - Laboratory Evaluation of the Complete Acceleration Gate System and a Report of Recent Circuit Developments," (Secret Title), NRL Report 5926 (Secret Report) Mar. 1963

43. Boyd, F.E., and Rohlfs, D.C., "A Very High Power Frequency Pulse Transmitter and Antennas," (Unclassified Title) NRL Report 5903 (Secret Report) 2 May 1963

44. Gager, F.M., Guthrie, R.C., Headrick, J.M., Page, I.H., and Zettle, E.N., "A Proposal for an Operational HF Radar," (Unclassified Title) NRL Memo Rpt 1422 (Secret Report) 10 May 1963

45. Davis, J.R., Headrick, J.M., Rohlfs, D.C., and Utley, F.H., "A High Frequency Ionospheric Radar Study of High-Altitude Nuclear Detonations," (Unclassified Title) NRL Report 5962 (Secret Report) 28 May 1963

46. Davis, J.R., "Range Ambiguity Reduction in the MADRE Radar," (Unclassified Title) NRL Memo Rpt 1444 (Secret Report) 15 July 1963

47. Davis, J.R., and Utley, F.H., "The Use of an HF Lunar Reflection Circuit in the Study of Ionospheric Electron Density," NRL Report 5968 (Unclassified Report) 19 July 1963

48. Gager, F.M., Morgan, G.A., Tesauro, C.B., Skaggs, G.A., and Zettle, E.N., "MADRE Performance Part 3 - Observations of February 12, 1962," (Unclassified Title), "MADRE Performance Part 3 - Very Long Range, Over-the-Horizon Detection of Aircraft with the MADRE Radar," (Secret Title) NRL Report 5991 (Secret Report) 30 Aug. 1963

49. Headrick, J.M., Curley, S.R., Ahearn, J. L., Davis, J.R., and Ward, E.W., "HF Radar Echoes and Refraction Effects Due to Water and Propellant Releases in the Ionosphere," (Unclassified Title, Secret Report) NRL Report 6015, Nov. 22, 1963

50. Davis, J.R., "Range Ambiguity Reduction in the MADRE Radar, Part II-Initial System Evaluation," (Unclassified Title-Secret Report) NRL Memo Rpt 1500, Jan. 1964

51. Gager, F.M., Morgan, G.A., Headrick, W.C., Tesauro, C.B., and Zettle, E.N., "MADRE Performance Part 4 - Observations of February 15, 1962," (Unclassified Title), "MADRE Performance Part 4 - Very Long Range, Over-the-Horizon Detection of Aircraft with the MADRE Radar," (Secret Title) NRL Report 6019 (Secret Report) Jan. 27, 1964

[redacted]

52. Ward, E.W., Headrick, J.M., and Zettle, E.N., "A Method of Separating Approach and Recede Pulse Doppler Radar Echoes," (Unclassified Title, Secret Report) NRL Report 6079, Mar. 24, 1964

53. Davis, J.R., Headrick, W.C., and Ahearn, J.L., "A HF Backscatter Study of Solar Eclipse Effects Upon the Ionosphere," Jour. Geophysical Res 69 No. 1, pp 190-193, 1964

54. Davis, J.R., and Headrick, J.M., "A Comparison of High Altitude Nuclear Explosion Effects in the E-Layer with Variations in Geomagnetic Field Strength," Jour. Geophysical Res 69 No. 5, pp 911-916 , 1964

55. Davis, J.R. and Rohlfs, D.C., "Lunar Reflection Properties at Decameter Wavelengths," accepted May 1964 by Jour Geophysical Res

56. Brown, R.M. and Wright, B.D., "Microwave Antenna Basic Research," Report of NRL Progress, February 1964.